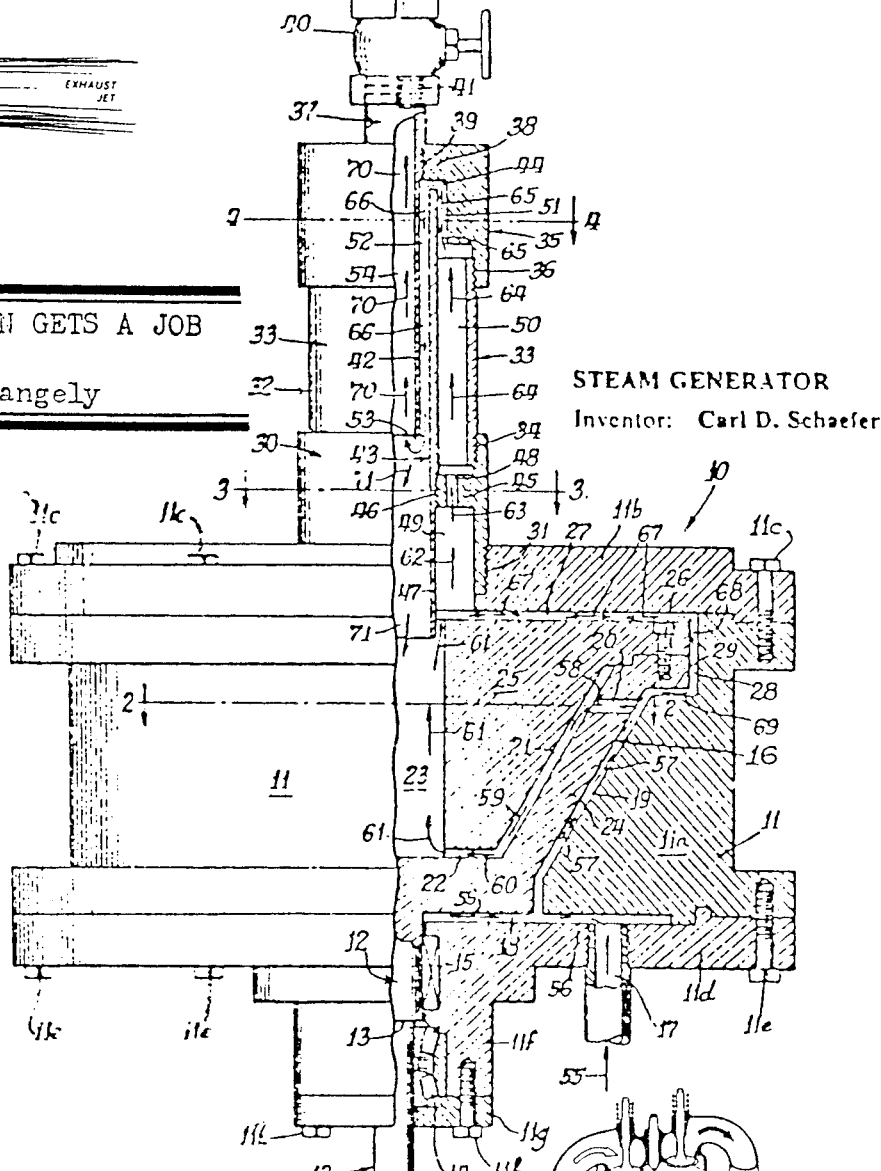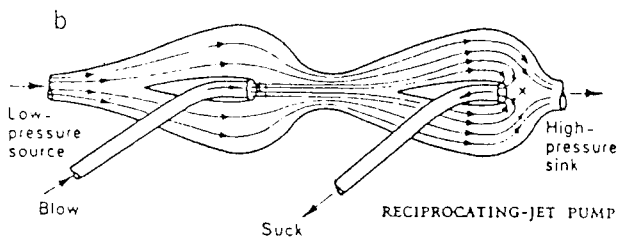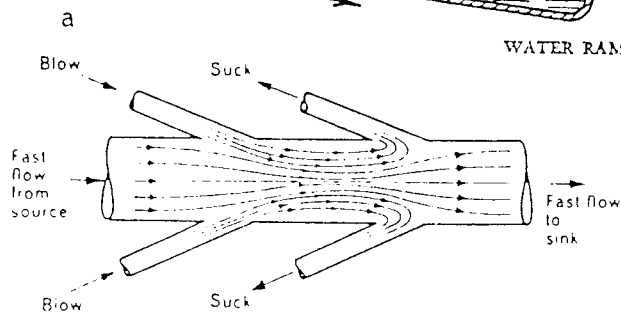Pulse-jet engine.

MAXWELL'S DEMON GETS A JOB

by Luther Rangely

Oscillating Loop Pump

WATER RAM

a

Blow   Suck

Fast flow from source

Fast flow to sink

Blow   Suck

b

Low-pressure source

High-pressure sink

Blow

Suck

RECIPROCATING-JET PUMP

STEAM GENERATOR

Inventor: Carl D. Schaefer
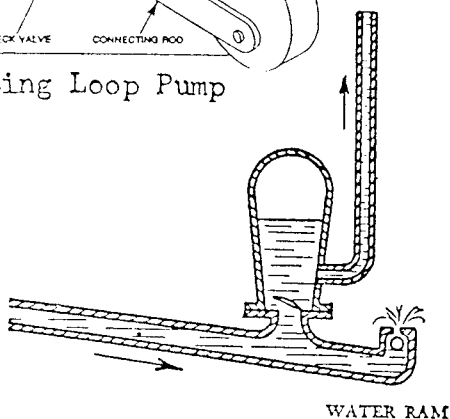
COMPREX pressure-wave machine, used for charging diesel engines

a = Engine
b = Cell-wheel
c = Belt drive
d = High-pressure exhaust gas
e = High-pressure air
f = Low-pressure air intake
g = Low-pressure gas outlet

Equalizer

INVENTOR.

Bob Neal
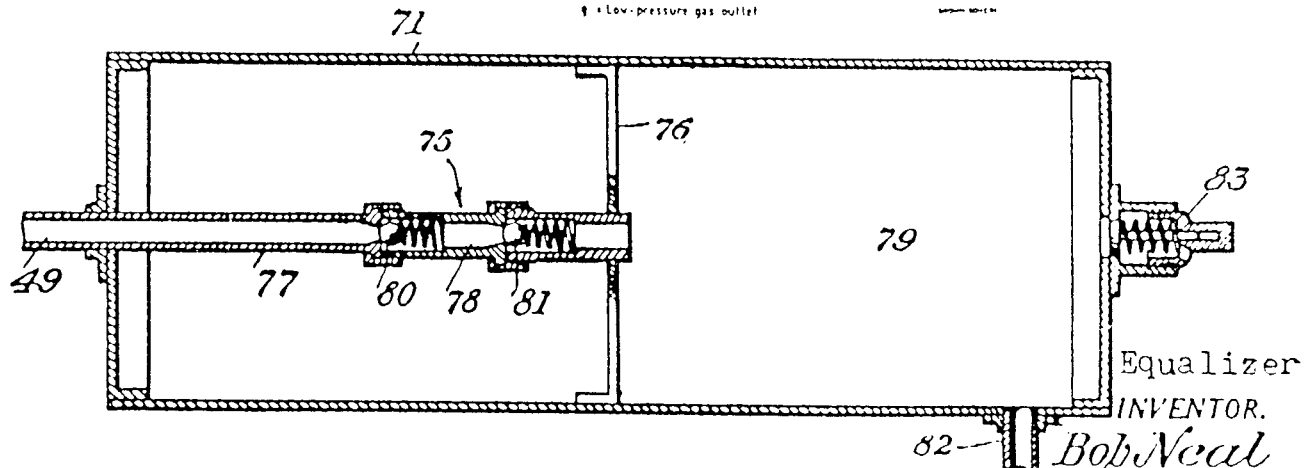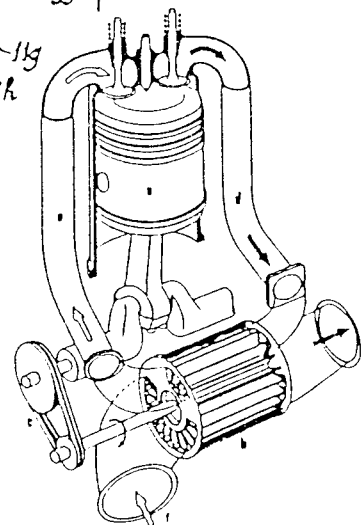
MAXWELL'S DEMON GETS A JOB
Secrets of the Self-fueling Air Car

by Scott Robertson

Introduction: O.K., LET'S KEEP IT SIMPLE

Chapter One

STALKING THE EQUALIZER

How I ignored what I already knew
long enough to figure it out for myself.

      I wanted to be the first person ever to build a car
that would run on air. I couldn't figure out how to do it,
but that didn't keep me from spending long hours with my cal-
culator, building what fantasy air cars my uneducated passion
could squeeze out of the few facts I thought I had.
      Back then in 1980, I'd just found out that not all people
called engineers drive trains. The laws of physics hadn't in-
vaded my safe world of wishes. I didn't know the difference
between Newton's Laws and Newton apples.

      My car's engine was going to run on suction pro-
duced by an enlarged version of the kind of blower used
in vacuum cleaners. The air motor's pistons would be
large bellows made of wood and cloth. I based my design on
the small "wind motors" used in the old player pianos that
I'd been rebuilding since age 13. The car would be made of
wood, and the drive power would come from the driver pedaling
a bicycle crank to turn the big blower fan.
      I believed there was a big oil war coming, and that
only a mass conversion to air cars could save the
world from strangling in its own greed-generated pollution.

1980
The author at the home of air car builder George Heaton.

When I told my boss we were all going to be pedaling wooden
cars to work, he just said, "More power to you," and went
back to reading his newspaper.
      My first idea for replacing the gas car had been to
somehow power the car with sound waves from huge loudspeakers.
      Toward the end of October, my co-worker Maria invited me
to Halloween dinner with her family at their home. She said
her husband, George, had built some air cars, and suggested I
talk to him about his experience. I couldn't believe that
someone else had thought of running cars on air. My elation
at finding a possible source for usable information made up
for my disappointment at not being the first.
      At the Halloween dinner, Maria told me that her husband
would choose his own time to bring up the topic. Some time

later, George told me he'd take me aside after he'd had a little more time to think. When he finally beckoned me to join him in another room, I was paying attention. Though I wondered if this might be a prank or a misunderstanding, he hadn't been talking long before I had my notebook out.

And there was no reason to think that either Maria or her husband was a prankster. I knew from spending long hours with Maria at the shop where we both worked that she was an intelligent, conservative working mother and the wife of a friendly and generous man of many accomplishments. As he began to reminisce, George was telling me that in 1969 he'd been the vice-president of the California Fuel Dealers Association. In that role, he'd testified before a legislative committee concerning the environmental dangers involved in the use of the catalytic converters needed with unleaded gas. He also warned me about compressor explosions, saying that one drop of oil contamination in an oxygen compressor could blow up a whole building. Unlike oxygen, compressed air isn't explosive, but he wanted to impress me with the seriousness of taking safety precautions when working with pressure equipment.

George told me that around 1949, he and a friend converted some motorcycles and cars to run on compressed air. They converted the existing gas engines to run on air, with several modifications that George described.

The cars they built "worked like perpetual motion machines." His wording seemed to imply that the car seldom or never ran out of air, that this is considered impossible by those who should know, that it obviously is not impossible because George has done it, and that it's still considered impossible by those who should know. The key to doing the impossible was to put low pressure air into a high pressure tank, without having to compress the air first, that is, without having to force it in against the resistance of the pressure in the tank. This allowed the use of small air pumps running off the car's motion to keep the tank full, while the engine ran off compressed air leaving the other end of the tank. George didn't remember exactly how to get low pressure air into a high pressure tank, but he thought a good compressor man could probably figure it out. He did recall that the air entered the tank in a stream of quick spurts, or pulses, and he thought it might have entered the tank "at an angle or something."

George and his friend "weren't engineers enough to know what pressures to use," and as a result they had trouble with their engines blowing up. That didn't keep them from driving their air cars across the country several times. The last time George was driving his air car across Nevada, a piston blew out the top of the engine, through the hood, and up into the sky, where it disappeared from sight. Since gasoline was so cheap at that time, the hassles and hazards involved in building experimental cars outweighed the disadvantages of buying gasoline, and they built no more air cars.

George suggested I get around the problem of converting existing engines to run on air, by using a 100 horsepower turbine air motor, which he said would weigh only 25 pounds. My later research turned up the 51A turbine air motor made by the Tech

Development Company of Dayton, Ohio, which fits George's description very well.

I left George's home with a head full of ideas, but without the background to put them to use, or even to properly research them. Because I didn't know how to confirm or deny George's claim to have achieved a perpetual motion effect, I eventually came to assume that he must be exaggerating, or dramatizing a hypothetical theory he wanted me to test out for him. But now, ten years later, my search for the self-fueling air car has brought me full circle, back to a working theory that I could almost have written from the notes I took that night at George Heaton's dining room table. The part George left out, the scientific explanation, would have become clear to me if I'd done any research on my idea of running cars on loudspeakers. If I'd studied the theory of sound waves more thoroughly when I was in piano tuning school, or when I was working in the pipe organ factory, it would have been obvious what I had to do to manifest the ideas that George left with me. In the meantime, believing that I didn't know how to design a self-fueling air car led me on a fascinating search through the nooks and crannies of compressed air history and pneumatic options. Each stumbling block along the way turned out to have not only a solution, but a really exciting solution that often turned out to be an advantage. I could only know so much about compressed air before becoming permanently interested in it. Each new finding has revolutionized my conception of what compressed air can do. Some of the most often-mentioned of compressed air's supposed disadvantages have turned out to be---from a new point of view---real advantages, and even sources of power.

For a few years after I met George Heaton, I sporadically devoted most of my spare time to a blind, groping search for something I didn't even have a name for. I learned nothing of consequence until I heard of Terry Miller's air car in late 1981 and began studying his design disclosure. Gaining my first clues as to what could and couldn't be done with compressed air, I gave up--I thought for good--the search for free energy.

In the Air Car Hall of Fame, Terry Miller will be remembered for being the first air car inventor to provide detailed building plans, documentation, and performance data for the education of the public. His writing persuaded me to stop looking for perpetual motion in compressed air, and to concentrate on such practical basics as increasing air engine efficiency, decreasing the weight of the components, etc. With the background I gained from studying Terry Miller's disclosure, I gradually learned where to look for answers to technical questions, and how to recognize answers when I saw them. By mid-1982, I'd been on the radio talking about Terry Miller's air car, and two friends and I had enthusiastically banded together to get rich quick building air cars that would go 200 miles between fillups.

Then we talked to an engineer. Or tried to. He refused to look at our design. He told us the government would never let us build air cars. He thought the public would be afraid of compressed air, and that a car with a broken tank would take off like a rocket ship. He pleaded with me to "let go." When he left, we were deflated for a day, but I managed to convince my friends

that, since he'd refused to look at our design, his comments were irrelevant to our project. So we found another engineer.

This time we learned of a problem related to our design, that we had failed to consider: **air has weight!** We already knew that, but had always assumed that its weight would be negligible. Our new engineer friend dolefully informed us that the amount of air we wanted to store on our car to make it go 200 miles between fillups would weigh 2500 pounds, or $1\frac{1}{4}$ tons.

At this point, my friends set the air car project on a far back burner, and I stepped back a ways myself, but only to recoup my permanent passion for air cars, and to look for new directions within the general goal of designing a marketable air car.

A few years later, in the summer of 1984, I found myself wondering why my friends and I had used a turbine air motor in our designs, since I couldn't remember having ever calculated the air consumption of Terry Miller's air engine. My inertia was overcome by a second wind of curiosity. I pulled out my air car files again, plugged in my calculator, and went back to work. The results were encouraging; I called Terry Miller and made an appointment to meet him and see his air car.

Terry said he would be busy, but that if I were to spend the afternoon with him, he might be able to give me an hour of his time. As it turned out, when I went to see him, he gave his full attention to our interview for five hours. Terry told me I was the first person who'd ever taken the trouble to study his design disclosure well enough to understand the key points, before coming to him with questions. We shared ideas on how to improve his air engine, and when I drove off, I was well satisfied with the results of our meeting.

On my way home from Crestline, where Terry Miller lived, I stopped in Lawrence, Kansas, at the University of Kansas Library where I liked to do my research. I was down in the basement where the old books were kept, absentmindedly flipping through some obsolete compressed air textbooks out of idle curiosity. I was astounded to discover that one of the books had a whole section on compressed air locomotives! I checked the book next to it on the shelf, and there was a whole chapter on these locomotives, which had been called "air cars" back around the turn of the century when they started to become popular for municipal transit. I took home a huge stack of old books that hadn't been checked out of the library in thirty years, astounded at my luck. It seemed as if introducing myself to Terry Miller had opened the floodgates for all kinds of information to start pouring in from new sources.

The next summer, Terry called me to order some piano wire for a new invention he was working on, and to invite me to help him demonstrate his air car at the energy exposition in Wichita. It was at this energy exposition that I discovered in person what a tremendous appeal air cars have to people. People lit up around the air car. The shiny electric car in the booth next to ours sat idle all weekend while people of all ages lined up for rides in Terry's makeshift prototype. The last ride I gave was to a blind man who got out of the car after his ride and memorized its layout with his hands.

Toward the end of the first day of the exposition, one of the air car's wheels stopped working, and we quit for the day

not knowing how to fix it in time to give rides the rest of the
weekend. But despite this setback, Terry's wife can confirm that
Terry was snoring as his head hit the pillow. In the morning he
suddenly stopped snoring with a loud snort, sat up and said, "It's
already fixed! The problem is the solution!" And he was right.
All we had to change was our perspective; it was so obvious we
hadn't seen it.
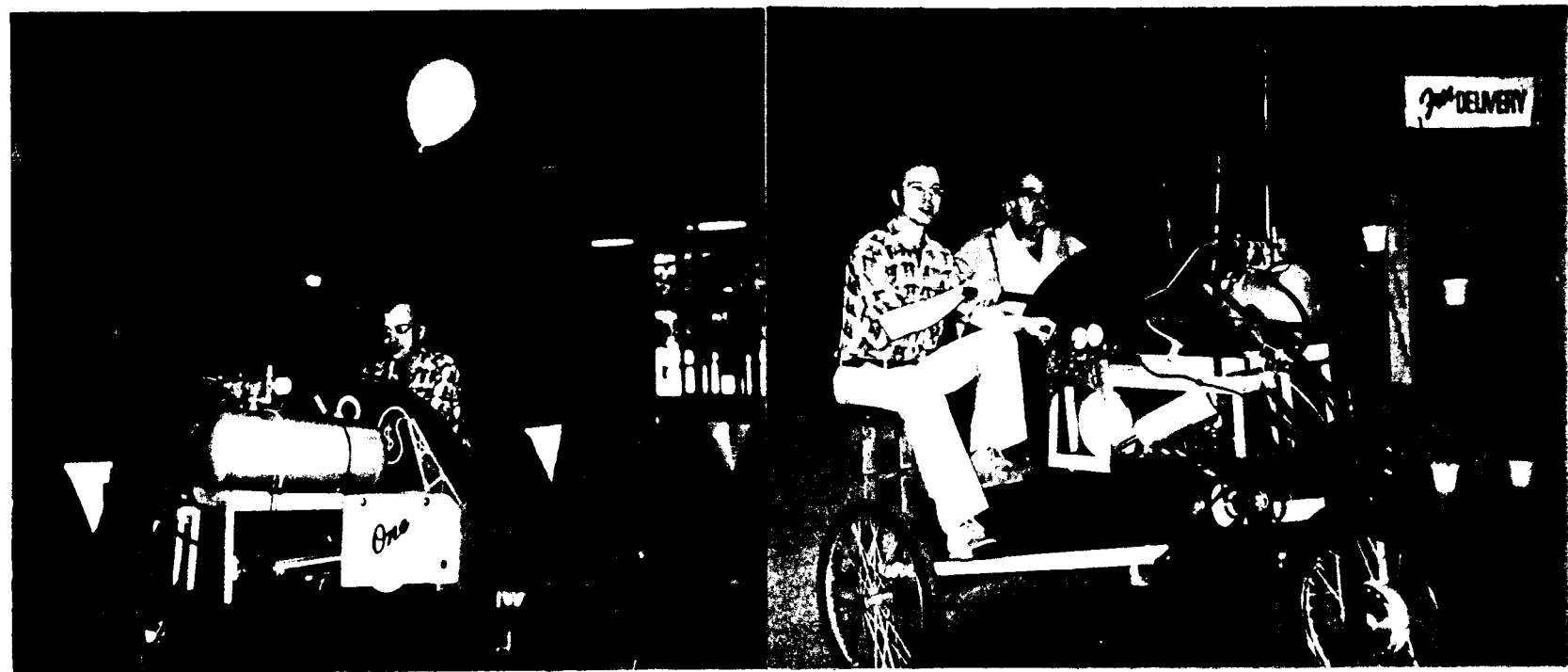
The author driving Terry Miller's air car.
Mr. Miller is pictured at right.

Terry Miller had introduced me to another researcher who had
been collecting information on air cars for several years. My
new correspondent had sent me a variety of articles, mostly maga-
zine and newspaper articles about inventors who claimed to have
built self-fueling air cars. Since the articles contained no docu-
mentation, building plans, or scientific explanations, I had filed
them under "history", wondering why so many seemingly normal,
intelligent people would all be making the same weird claim.
    The information my friend had sent me included some flyers
put out by Bill Truitt, whose air car had also been discussed in
a mainstream book, Auto Engines of Tomorrow, by Harris Edward
Dark. Truitt had put out flyers containing his phone number,
unlike the other inventors who were bogged down in secrecy. So
on March 30, 1986, when I decided to compile my research into a
book, the first thing I did was to call Bill Truitt, in order to
"complete" my research.
    Truitt built his first self-fueling air car at the age of
seventeen, in 1920. By 1974, he "pretty much had the bugs worked
out." In order to eliminate certain problems brought on by his
sudden fame during the gas crisis in the 1970s, he sold his de-
sign to the US Army and NASA. Bill Truitt feels he's served his
country by not shocking the US auto makers with a new contender,
and by not giving his secret to the Japanese.

6

Bill had no problem talking about his air cars for at least a half hour, but when it came to the scientific explanation I was after, he would start speaking in vague terms, or he would change the subject. As far as I could tell, my skepticism didn't affect his response one way or another. Because his style of communication bore no resemblance to that of the liars, con artists, and big-talkers that I've met, and because he seemed to be intimately familiar with the details of his claimed accomplishments, I believed him. He didn't act like he had anything to prove, and didn't try to sell me anything. His manner was moderate and lucid. He seemed to me like a perfectly normal 83-year old inventor.

I began a search for a hole in physics, or in the nature of automobiles, or in the nature of compressed air, from which I could extract a working free energy machine. For three months, I lived in my car, travelling to other states to visit their libraries, racking my brain for some way to keep an air tank full without having to mechanically squish the incoming air to get it in.

I started making some headway when I realized that atmosphere could be compressed non-mechanically, that is, without being squished together by a compressor: by being mixed with air that had already been compressed. I built my first compressed air device, calling it an equalizer, since its purpose was to raise the pressure of atmosphere without squishing its molecules together, instead raising the pressure of the incoming atmosphere by equalizing its low pressure with the higher pressure of the compressed air with which it was mixed.

The author's equalizer: piston retracts to suck in atmosphere; valve opens to add compressed air from a tank to cylinderful of atmosphere. Piston then pumps cylinder contents back into tank, thus replacing compressed air used for mixing and adding a cylinderful of atmosphere to the tank. Clumsy way to get low and high pressure air to mingle. A basic idea like this could have led Hudspeth and Lunsford to their air amplifier, a similar equalizer whose pistons are powered by compressed air and springs, instead of by a shaft. Their design also uses a pulsating jet pump to get the two unequal pressures to mix.
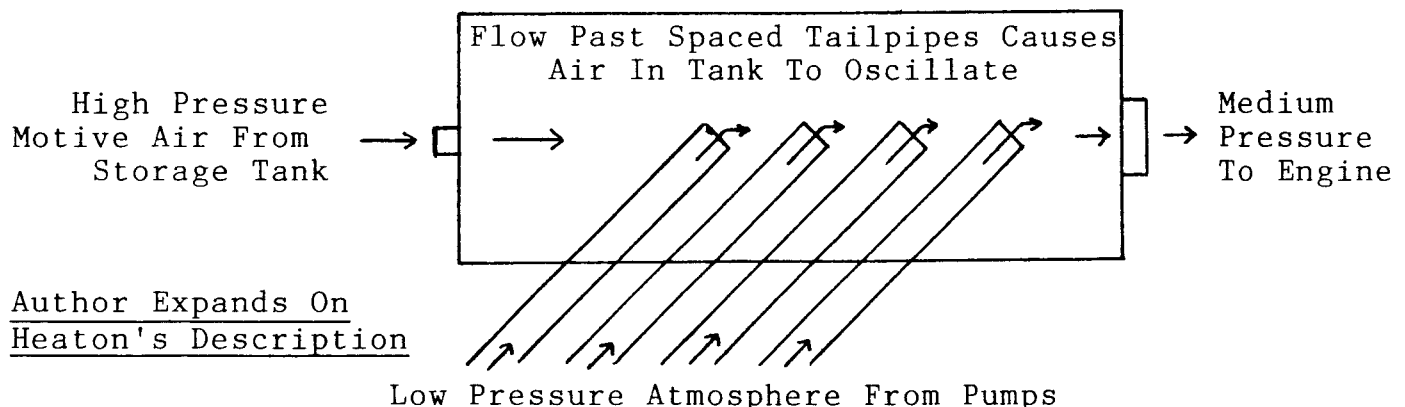
Photo by Kathleen Leibensperger.

But I couldn't afford the equipment I needed to test my ideas in ways that would yield clearly unambiguous results. Instead, I returned to the task that had prompted me to call Bill Truitt to begin with. I absorbed myself in compiling my research findings into a book. For weeks, I sat at my workbench with scissors and rubber cement, the floor around me piled high with scraps of photocopy paper that I'd cut away from the raw material of my passion. I compiled a 377-page book, called it Air Car Access, Volume One: Documentation, and notified practically everyone I knew that my book was available, handbound in mahogany covers.

As soon as the book was finished, I started finding possible solutions in it to the problem of absorbing extra energy into a compressed air medium. Mainly I discovered the importance of ambient heat to the compressed air locomotive power plants that were used more and more in coal mines up to the 1930s. Ambient heat is the low-level, dissipated heat contained in ordinary atmosphere. During the 1920s, there were hundreds of these compound air engines being used in mining throughout the coal fields of Europe and the United States. For several months, I spent most of my spare time and money researching the compound air engine. I wrote a pamphlet called The Solar Air Car, and advertised it in The Mother Earth News.

By the winter of '86-'87, I was corresponding with fellow researchers from Florida, Canada, and Australia. My friend in Florida had earlier sent me the Truitt flyers and other articles on inventors of self-fueling air cars. Then he introduced me, by way of a three-way phone conversation, to a man in California who has been stalking the self-fueling air car for forty years! My new contact had seen a few different air cars and knew of no design he could personally recommend except Bob Neal's. He had known Neal, and had no doubt of the genuineness of his invention.

My Florida correspondent got busy and found Bob Neal in the US Patent Gazette, and sent me the patent number. I ordered a copy of the 1936 patent. Its arrival in my mailbox took me full circle back to that night at George Heaton's home. Bob Neal's patent unmistakably describes a means for getting low pressure air into a high pressure tank, without having to mechanically push the low pressure air into the tank, without having to work against the resistance of the compressed air already in the tank.

When Neal tried to patent his Compression Unit, the patent office turned him down, since he seemed to be claiming a perpetual motion device. So Neal built a miniature working model and took

Flow Past Spaced Tailpipes Causes Air In Tank To Oscillate

High Pressure Motive Air From Storage Tank

Medium Pressure To Engine

Author Expands On Heaton's Description

Low Pressure Atmosphere From Pumps

it to the Patent Commissioner's office in Washington, D.C. He
showed the Commissioner's patent inspectors a working engine, and
they granted him a patent. But Neal's patent papers omit the
same information that George Heaton and Bill Truitt left out:
the scientific explanation of **why** their air cars were able to keep
their own tanks full. After a brief attempt to extract hidden
meaning from the patent papers' terse descriptions and drawings,
I set the question on the back burner and continued researching
the solar air car.

It was during a research trip early in 1987 that I caught
myself visualizing Neal's equalizer in operation--and it was
working! I stepped back into the daydream, and realized that I'd
seen the same principle operating in my mind before, when George
Heaton had described putting low pressure air into a high pres-
sure tank "at an angle or something." In both scenes, I saw the
motion of the air inside the tank surging past the outlet of the
air intake pipe that extended into the tank. The air leaving the
tank would leave behind it a jetstream or whirlwind in the tank,

The author driving the
air car he designed
and built in ten hours.

Below: the author's
first model of Neal's
equalizer tank.

Photos by Susan Myers

The author is available
on a limited basis as a
research consultant in
the general field of
high efficiency power
pneumatics. He is not
a trained specialist in
any field directly re-
lated to air cars ex-
cept piano tuning. De-
spite his fortunate lack
of formal schooling, he
may be more well-rounded
in the knowledge of the
history of compressed
air vehicles than anyone
else on Earth.

dragging the intake air into the tank in its wake.

In the spring of 1988, I was trying to convince an engineer friend that the equalizer could work according to the Venturi Effect. The Venturi Effect is the action of a steadily flowing motive fluid inducing a lower pressure fluid into its wake, causing the two fluids to mix and equalize in pressure. The engineer thought I should take my own experimental results more seriously; I had built a Neal equalizer tank to use the Venturi Effect, and it was incapable of inducing, or entraining, low pressure air. I still wanted to think the device was trying to work, because of a gauge reading I'd been getting.

My friend's dauntless skepticism prompted me to take a closer look. I re-did the math I'd been using to buoy up my belief in my equalizer theory, and found my mistakes; the assumptions I'd been making based on that math were invalid. Then I designed new tests to try to **dis**prove my optimistic interpretation of the gauge reading. The tests showed that the gauge had been saying the right thing for the wrong reason. The working model could no longer be construed to be working, by any stretch of the imagination.

I thought back over what my engineer friend had told me. He'd been harping on the theme that, if the equalizer were going to work at all, it would probably only work under very limited and particular conditions. As an example, he mentioned the pulsejet, a type of jet engine, which is made of a tube that must be exactly the right length to contain the "shock wave" that makes it work. In the faint hope that the engineer might have been telling me something of importance, I pulled out my one-page file on pulsejets. The cloud of disappointment and disillusionment that had recently fallen over my research lifted quickly as I found myself reading about equalizers called pulsejets!

This new lead opened up whole new realms of ideas to research. With boxes full of photocopies to read and a cold, rainy spring to keep me home when I wasn't running up and down stairs at the library, new ideas poured through me and possible explanations popped into my head, making me write and think and read and hypothesize from dawn to dusk. I found dozens of references relevant to my newfound fluid wave explanation for getting low pressure air into a high pressure tank, some of them right on my own bookshelf. I found out there was not just one, but at least three standard methods for getting low pressure water into a high pressure steam boiler without a pump. Some of the things that can be done with fluids and the impetus of resonance and sound waves seemed as incredible as what Neal claimed to have done with his equalizer.

It was during this period of research, just before the working model started working, that I finally discovered the concept of Maxwell's Demon.

James Clerk Maxwell was a moderately eccentric Scottish physicist who lived until 1879. His breakthroughs in thinking about the physical world have become the backbone of a good part of modern physics. It was Maxwell who figured out that magnetism, electricity and light are all **waves** on the same spectrum. His most controversial—and least developed—idea, which has come to be called Maxwell's Demon, has turned out to be a way of using

waves in air, to make the self-fueling air engine he discussed in 1870 a practical reality. Maxwell's point was to show that the Second Law of Thermodynamics could be gotten around somehow. This law stated that you can't ever re-use the same energy for the same thing indefinitely, because during use some energy must dissipate, becoming unavailable for re-use. Everything has to have a constant input of concentrated energy from a source outside itself to keep going. Maxwell said this might not always be true.

Maxwell proposed that one might imagine a tiny being (>demon) inside a tank of air that's divided into two parts by a partition. The demon operates a tiny gate in the partition, letting only relatively fast, dense, or hot units of air go through the gate into the other half of the tank. At the expense of whatever energy the demon uses to sort tiny units of air, one could operate an air engine on the pressure and temperature difference between the two parts of the tank.

A 1967 article in <u>Scientific American</u> starts by pointing out that if Maxwell were correct, the economic consequences would be far greater than those resulting from nuclear power, and that "a few decades ago a nuclear power station would have been considered a project equally fantastic." The article goes on to explain how physicists had, by 1951, concluded that Maxwell's demon was impossible. In light of Bob Neal's simple invention and my discovery of its operating principle, I've concluded that these physicists were out in left field somewhere, operating in the nether-worlds of abstraction; they mentioned no hardware, performed no experiments, and put forth no testable hypotheses. Like Maxwell himself, they didn't dig too deeply into the implications of this novel idea as a possibility; they only went in circles around the idea, abstractly reasoning that the tiny being couldn't see to sort air molecules inside the dark tank. Their overspecialized point-of-view proved no match for my optimistic ignorance.

The piles of research I was collecting on fluid wave technology was inspiring, and illuminating in a general way, but most of my findings weren't directly applicable to an explanation of exactly how and why Neal's equalizer was able to work. In frustration, I turned back to Neal's patent, which I'd always thought was unimportant except for the description of the equalizer itself. I'd assumed that the majority of the patent, which described the air engine and compressor cylinders and valves, only served to flesh-out the description of the equalizer, and possibly to camouflage its importance. The equalizer is the demon in the tank.

But now that I knew what to look for, the patent as a whole finally began to make sense to me. With clarification from my researcher friend in Canada, who had read the patent more carefully than I had, and with some important further elucidation from the engineer friend who had led me to the sound wave explanation, I eventually came to a much more complete understanding of what, specifically, the equalizer in my workshop was doing to get low pressure air into a high pressure tank.

That's how Maxwell's Demon got a job, and how I got a job as an air car consultant. The rest of this book explains in more specific and technical terms exactly what sound waves have to do with Maxwell's Demon and self-fueling air cars.
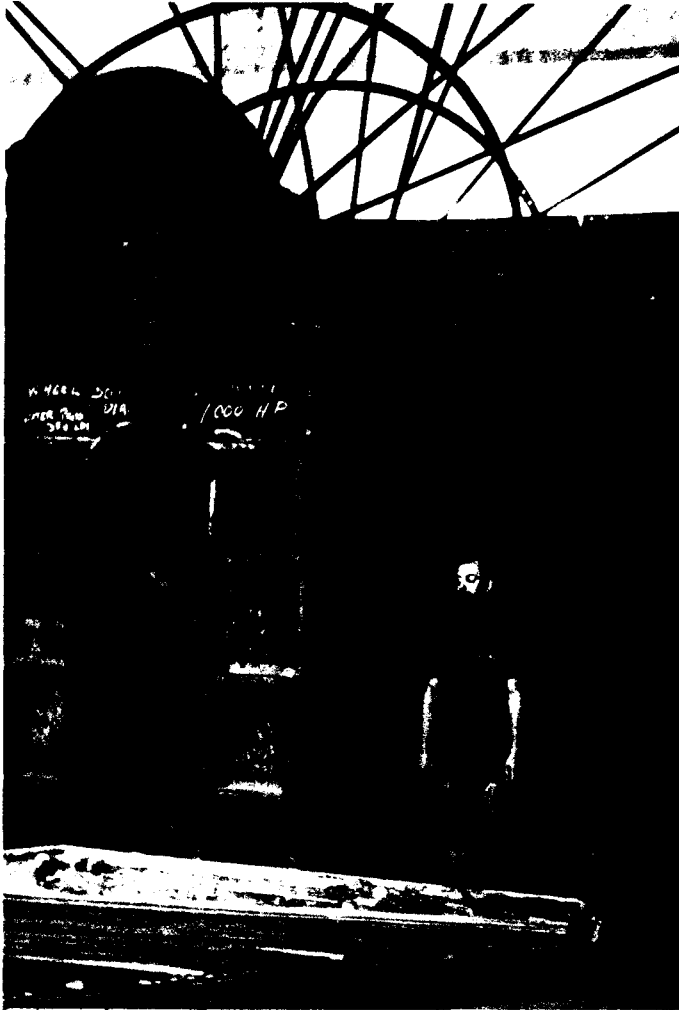
The author standing on front of the Pelton wheel at the North Star Mine in Grass Valley, California. This is the largest Pelton water wheel in the world, and was used continuously for 30 years to compress air for the North Star and Empire gold mines.

Photo by Kathleen Leibensperger

The author seated at the one-lever control panel of a compressed air locomotive used to haul ore cars at the Empire Mine.

Photo by Susan Myers
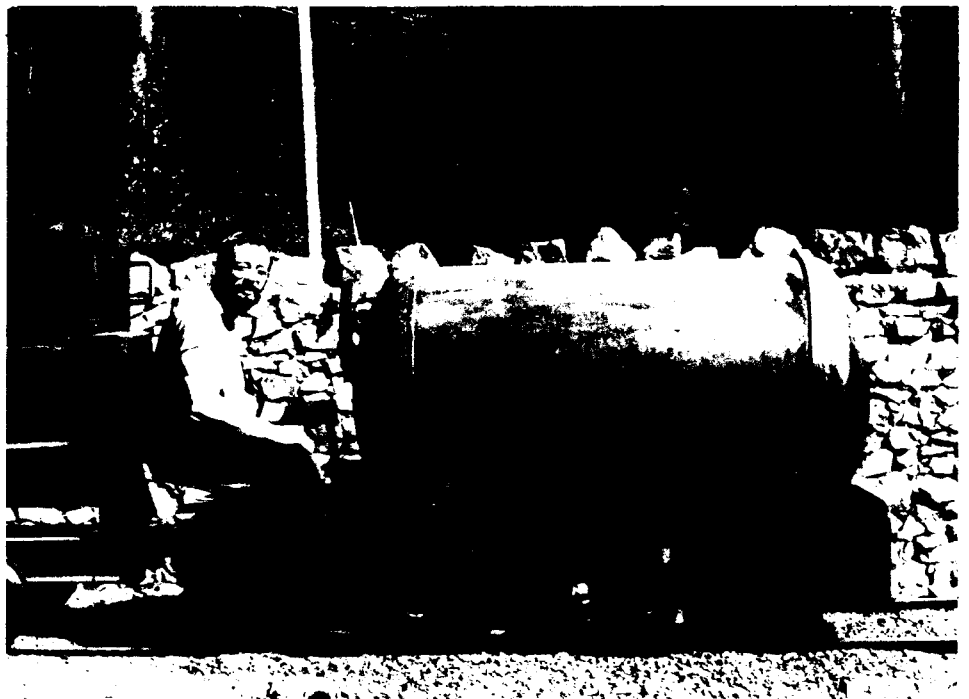
Theoretical Horse Power Required

Single-stage Compression

FOR COMPRESSING ONE CUBIC FOOT OF FREE AIR PER
MINUTE (ISOTHERMALLY AND ADIABATICALLY)
FROM ATMOSPHERIC PRESSURE (14.7 POUNDS)
TO VARIOUS GAUGE PRESSURES

Gauge Pressure Pounds	Absolute Pressure Pounds	Number of Atmospheres	Isothermal Compression Mean Effective Pressure	H. P.	Adiabatic Compression Mean Effective Pressure Theoretical	Mean Eff. Pressure plus 15% Friction	H. P.	H. P. plus 15% Friction
5	19.7	1.34	4.13	0.018	4.46	5.12	0.019	0.022
10	24.7	1.68	7.57	0.033	8.21	9.44	0.036	0.041
15	29.7	2.02	10.31	0.045	11.46	13.17	0.050	0.057
20	34.7	2.36	12.02	0.055	14.30	16.44	0.062	0.071
25	39.7	2.70	14.68	0.064	16.94	19.47	0.074	0.085
30	44.7	3.04	16.30	0.071	19.32	22.21	0.084	0.096
35	49.7	3.38	17.90	0.078	21.50	24.72	0.094	0.108
40	54.7	3.72	19.28	0.084	23.53	27.05	0.103	0.118
45	59.7	4.06	20.65	0.090	25.40	29.21	0.111	0.127
50	64.7	4.40	21.80	0.095	27.23	31.31	0.119	0.136
55	69.7	4.74	22.95	0.100	28.90	33.23	0.120	0.145
60	74.7	5.08	23.90	0.104	30.53	35.10	0.133	0.153
65	79.7	5.42	24.80	0.108	32.10	36.91	0.140	0.161
70	84.7	5.76	25.70	0.112	33.57	38.59	0.146	0.168
75	89.7	6.10	26.62	0.116	35.00	40.25	0.153	0.175
80	94.7	6.44	27.52	0.120	36.36	41.80	0.159	0.182
85	99.7	6.78	28.21	0.123	37.63	43.27	0.164	0.189
90	104.7	7.12	28.93	0.126	38.89	44.71	0.169	0.195
95	109.7	7.46	29.60	0.129	40.11	46.12	0.175	0.201
100	114.7	7.80	30.30	0.132	41.28	47.46	0.180	0.207
110	124.7	8.48	31.42	0.137	43.56	50.09	0.190	0.218
120	134.7	9.16	32.60	0.142	45.69	52.53	0.199	0.229
130	144.7	9.84	33.75	0.147	47.72	54.87	0.208	0.230
140	154.7	10.52	34.67	0.151	49.64	57.08	0.216	0.249
150	164.7	11.20	35.59	0.155	51.47	59.18	0.224	0.258
160	174.7	11.88	36.30	0.158	53.70	61.80	0.234	0.269
170	184.7	12.56	37.20	0.162	55.60	64.00	0.242	0.278
180	194.7	13.24	38.10	0.166	57.20	65.80	0.249	0.286
190	204.7	13.92	38.80	0.169	58.80	67.70	0.256	0.294
200	214.7	14.60	39.50	0.172	60.40	69.50	0.263	0.303

Fig. 23.

COMPRESSED AIR DATA — AIR COMPRESSOR TABLES

Theoretical Horse Power Required

Three-stage Compression

FOR COMPRESSING ONE CUBIC FOOT OF FREE AIR PER
MINUTE (ISOTHERMALLY AND ADIABATICALLY)
FROM ATMOSPHERIC PRESSURE (14.7 POUNDS)
TO VARIOUS GAUGE PRESSURES

NOTE:—Table for Adiabatic Compression assumes intercooling back to the same initial temperature for each stage.

NOTE:—Isothermal horse-power is unaffected by the number of stages of Compression.

Fig. 25.

Theoretical Horse Power Required

Two-stage Compression

FOR COMPRESSING ONE CUBIC FOOT OF FREE AIR PER
MINUTE (ISOTHERMALLY AND ADIABATICALLY)
FROM ATMOSPHERIC PRESSURE (14.7 POUNDS)
TO VARIOUS GAUGE PRESSURES

NOTE:—Table for Adiabatic Compression assumes intercooling back to the same initial temperature for each stage.

NOTE:—Isothermal horse-power is unaffected by the number of stages of Compression.

Fig. 24.

Boyle's Law: at constant temperature, pressure and volume changes are defined by p x v = constant.

As to the precise way in which a fall of pressure in the mains influences the efficiency there is a word to be said. If air enters an air main at 60 lbs. per sq. in. gauge pressure and reaches the other end at 55 lbs. gauge pressure, there being a fall of pressure of 5 lbs. due to friction, then it is commonly stated that five-sixtieths of the energy of the air is wasted. But this is altogether erroneous, the statement being based on a false hydraulic analogy. With the fall of pressure in the case of air there is an expansion of volume which largely compensates for the loss of pressure. The intrinsic energy of the air from which the work of the air motor is borrowed remains constant. It is only because the air motor works against the pressure of the atmosphere, that the available energy of air at 55 lbs. is less than that of air at 60 lbs. pressure.

Unwin, The Development and Transmission of Power from Central Stations, 1894

Chapter Two

JARGON-INVOTING FAILS TO LIMIT PNEUMATIC OPTIONS

How can you say what you mean when the terms
that the scientific establishment has provided
for describing compressed air with are already
saying it all wrong, and that's the only reason
you had anything to say to begin with?

If compressed air is so great, then why have its few die-hard
champions found no audience among the educated? What is it about
the way society trains its technicians and engineers that keeps
them reciting the slogan that "compressed air is inefficient"?
Within the context of making and using compressed air, there
are several different efficiencies; the term "efficiency" in iso-
lation is meaningless. To simply assert that "compressed air is
inefficient" is to claim the unsupportable: that compressed air
is inefficient in every way and in every application, that it will
always be inefficient, that there's nothing anyone can do about
it, ever. Could this be possible? Is the Earth flat?
I would be the last to insult the educated professional
scientists of centuries past, whose knowledge of the Earth's
flatness was duly supported by empirical observation: go outside
and look around. Obviously, the Earth is flat. Nor would I take
lightly the many years of difficult training today's engineers
must go through before they're qualified to look at the information
that's available to them, from the vantage point they've been
trained to look from, and say, "Ah yes, indeed, compressed air
is inefficient."
Modern engineering textbooks are so clogged with abstraction
and advanced mathematics that only engineers and mathematicians
can use them. I'm not complaining; this is unavoidable, and will
only become more so as society moves from high tech to higher tech.
But why do modern textbooks dispense with the technical and mathe-
matical description of the factors involved in computing the air
consumption of air motors? Compressed air textbooks haven't of-
fered any information on state-of-the-art air engines since 1930.
The only occurences of the term "air engine" in modern textbooks
are as mental constructs used in teaching elementary thermodyna-
mics. Industry has dismissed compressed air as "inefficient",
and therefore suitable only for special applications, because
almost all modern air motors are designed for portability and con-
venience, not for efficiency. Companies that manufacture air
motors advertise their products as "efficient". This raises the
question, efficient **compared to what?** If today's air motors are
efficient, then the air **engines** of 1920 were **extremely** efficient.
To make and use compressed air efficiently requires designs
built on a thorough familiarity with what has been done in the
past. Ask almost any engineer about compressed air for running
engines, and what will click into place in his mind is a well-
engineered house of illusions built of the limitations and ima-

gined limitations of modern pneumatic technology. It's not his fault he didn't study the books published on compressed air before 1930; his teacher didn't study them either. The textbooks of today aren't wrong; they're just not written in the context of air as a prime mover, since petroleum fuels and electricity have been, till recently, the only prime movers needed. But pollution, the growing scarcity of raw materials, and the economic crises resulting from monopolization of energy sources have reestablished the pre-1930 need to concern ourselves with finding the **best** ways to make and use power.

In this chapter, I'll identify some of the deletions, distortions, and generalizations about compressed air that have led to its reputation as an anemic energy carrier. I'll translate the textbook basics on compressed air into language that any mechanically inclined person can understand. Then to illustrate how education can obscure possibilities, I'll discuss the efficiency of jet pumps. Then I'll guide you through a shift of perspective on "perpetual motion" air cars, which are actually solar power plants, no more mysterious than the photovoltaic cells, windmills, and heat pumps that we take for granted.

Squeezing air molecules together produces more than pressure. It produces lots of heat, too. Then as it expands back to atmospheric pressure, which it would do in a maximally efficient air engine, the air cools the same amount that it heated up during compression. The process of compressing or expanding air is categorized in relation to what happens to the heat or cold produced in the process. "Adiabatic" (which rhymes with "bat-in-the-attic") means that all heat or cold stays in the air. An adiabatic compressor would have insulated cylinders. "Isothermal" means that all heat or cold leaves the air. The cylinders of an isothermal compressor or engine would be finned to radiate heat through the walls of the compressor cylinder, or to absorb the ambient heat of the atmosphere through the walls of the engine cylinder, warming the air inside the cylinder that expands to push the piston.

All the heat that adiabatic compression makes will still be in the air delivered to the tank. The textbooks assume that all this heat will then dissipate to the surroundings through the walls of the tank. This assumption creates the prevailing illusion that adiabatic compression is inherently less efficient than isothermal compression. This is because it takes more energy to compress hot air than cold, for a given yield of compressed air. The warmer the air is before compression, the more of the energy used to compress it will make heat, and the less to make pressure. Assuming that this heat is useless, then adiabatic compression is maximally inefficient. But as one old textbook points out, adiabatic compression would be preferable if the air were to be used immediately upon being compressed. Hot air provides more energy to push an engine's piston than does cold air. A modern textbook writer briefly raises his head above the muddy waters of convention to remind us that compressor installations can be nearly 100% efficient if compression heat is conserved. So-called "waste" heat can serve as fuel to any air engine, but only if conserved and directed to that purpose by the system's design.

The other idealized extreme, isothermal compression, is universally considered the more efficient of the two extremes, but

Cost Effectiveness

IN TERMS of specific energy requirement the cost of compressed air is somewhat higher than that of electricity. However, taken in isolation, direct costs of energy are only part of the overall question of cost-effectiveness, which must cover utilization (compressed air systems being suitable for some jobs where electricity is not; or in direct competition with electric motors in other cases, for example); capital costs and depreciation; overall efficiency; reliability; and operating costs (maintenance and labour). Cost-effectiveness aims at optimizing all parameters; and more particularly instituting savings when possible.

It is, for example, possible to achieve near 100% overall efficiency with a compressed air installation. This can be done by recovery of the compression heat generated in the production of compressed air.

this conclusion starts with the assumption that all compression heat is lost. Isothermally compressed air enters the tank at the same temperature at which it entered the compressor. The cooling required for this process can be provided by any means or combination of means that removes heat from the air before, during, and after compression. The more effectively the compressor dissipates compression heat, the less total heat build-up there will be, and the less power will be needed to compress a given volume of air to a given pressure. In practice, isothermal and adiabatic are conceptual extremes never actually reached. Real compression and expansion fall somewhere between the two extremes. Overgeneralizing the benefits of wasting compression heat has led to the paradox that isothermal compression is automatically considered more efficient than the potentially more conservative process of adiabatic compression.

Adiabatic expansion in an air engine could be aimed for by insulating the engine cylinders to keep ambient heat from entering the cylinder through its walls. But cold air contains less energy for pushing the piston than does hot air. The cold cylinder walls would absorb heat from each incoming pulse of air, robbing it of much of its power. Besides this subtle disadvantage is the practical problem that air entering the engine cylinder at ambient temperature would drop to way below the freezing point of water before expanding completely. This would cause the water content of the compressed air to block the engine's exhaust ports with ice. This is why modern air motors are purposely designed to only partially expand compressed air before exhausting it. In order to use all the pressure supplied to them, the expansive air engines built in the first part of this century used cut-off valving. Cut-off valve gear admitted compressed air to the cylinder during only the first part of the piston's stroke, then the intake valve would close so the air just admitted could expand fully to atmospheric pressure before leaving through the exhaust port. If it were perfectly insulated, such an engine would be adiabatic.

Because of the problems resulting from sub-freezing temperatures, expansive air engines which were used in metropolitan transit locomotives and for various stationary applications employed

some means of reheating compressed air on its way from the tank to the engine. Reheating refers tacitly to the loss of compression heat due to isothermal compression. If it were possible to conserve all compression heat, then short cut-offs in expansion engines would result in the air leaving the engine cylinder at the same pressure and temperature at which it had entered the compressor. The various reheating schemes all had in common the burning of coal as the source of heat. It was eight times cheaper to increase the energy content of a tankful of air by reheating, than it would have been to provide the same energy increase by compressing more air. Compressing more air would make more waste heat to get rid of; heat added to air on its way to the engine was totally usable as fuel.

Despite the small cost of reheating air, it was a nuisance in practice. One of the main methods of reheating was to heat water at the air station where the locomotives stopped to fill their tanks. When the engine stopped for air, it would also fill a special tank with hot water. The compressed air would bubble through the water tank on its way to the engine. A later method was to inject controlled amounts of hot water into the air. Such practices were unfortunate complications of the air car's inherent simplicity. This led to Charles Bowen Hodges' invention of the atmospheric interheater, which I call the ambient heater. The ambient heater eliminated the burning of coal to reheat air, made adiabatic expansion's chief drawback an advantage, and added isothermal expansion to the air engine's cycle to provide it with lots of free fuel from its surroundings.

The Hodges engine welcomed the adiabatic production of cold. The cold air exhausted from the cylinder entered a long closed cylindrical tank, the ambient heater, instead of exhausting to the atmosphere. The ambient heater contained many long tubes that were open at both ends to atmosphere. Atmospheric air, which was much warmer than the cold engine exhaust, flowed continuously through the tubes. In this way, dissipated solar heat and industrial waste heat from the atmosphere surrounding the engine was readily absorbed by the cold, partially expanded compressed air, increasing its energy content by 30%. Then the compressed air was used to push another engine cylinder. By eliminating coal-burning reheating schemes with a little common sense, C.B. Hodges and the H.K. Porter Company introduced a non-polluting solar technology before its time.

In 1921, there were over 150 of these compound air-powered locomotives in use in the coal mines of Kentucky and West Virginia. Meanwhile, European companies had taken Hodges' invention much further by building triple expansion, or three-stage air engines. By using the same compressed air successively in three cylinders, with an ambient heater adding free energy to the compressed air before all three cylinders, these engines increased the driving range of locomotives by 50-60%. In Germany there were 624 triple-expansion air-powered locomotives working in one coal-mining district alone.

Some modern engineers, having never heard of efficient air motors, would scoff at the news that free energy used to supply these old contraptions with a full third of their energy supply. But here's what a pneumatics engineer, A.E. Chodzko, wrote in

the January 1899 issue of <u>Modern Machinery</u>: "There is nothing
abnormal to an efficiency greater than 1 [100%], when reheating
is used; this will occur (regardless of pipe and other friction)
whenever the temperature of reheating is higher than the tempera-
ture of compression." Now let the scoffers chew on the following
passages from Barnard, Ellenwood, and Hirshfeld's classic textbook
<u>Heat-Power Engineering</u> (1926): "The temperature decrease in any
real [air] engine will not be equal to the adiabatic, because heat
will be supplied to the engine cylinder from the surrounding at-
mosphere [through the cylinder walls] and will tend to make the
expansion somewhat more nearly isothermal. If the engine could
be run with extreme slowness the expansion would very closely
approach a true isothermal. ...The object of using the air ex-
pansively is to utilize some of the internal energy [see below]
of the working substance which enters the engine. If the expan-
sion is isothermal no work can be done at the expense of such
energy; on the contrary, heat equivalent in quantity to the work
done during the expansion period must be supplied from an external
source. With an adiabatic expansion, however, all of the work
done during such an expansion will be at the expense of the
internal energy of the gas. The apparent discrepancy between
these two cases is due to the fact that during the isothermal
expansion it is assumed that the required amount of heat is sup-
plied from the atmosphere, and that it costs nothing, and may,
therefore, be freely used..." In other words, if an air engine
runs slowly enough, **all** the energy used to push the piston will
be replaced spontaneously by ambient heat entering the compressed
air through the cylinder's walls, and the air will leave the cylin-
der at the same temperature and pressure at which it entered the
cylinder, available for re-use. This is **not** perpetual motion;
it's solar power.

The term "internal energy" is of great importance in under-
standing the energy source of the self-fueling air car. Air is
made of molecules. When you heat air, its molecules move around
faster and bump into each other harder. At the temperature of
absolute zero, which is 461° below 0° F., air molecules stop mo-
ving, stop bumping into each other, and contain absolutely no
heat. Internal energy is the amount of energy contained in a sub-
stance due to the activity of its molecules. One pound of air at
the absolute temperature of 0° contains 0 x 1 = 0 internal energy.
Internal energy measures only the temperature (molecular activity)
of a given quantity of a gas.

To calculate the internal energy of air at normal temperature
ranges, I must introduce the term "specific heat". Without going
into too much detail, I'll just define the term as .2375 B.T.U.s,
which is the amount of energy it takes to raise the temperature
of one pound of air by 1° F. There's more to it than that, but
that's all you need to know to understand internal energy, except
that 1 B.T.U. = 778 ft-lb; B.T.U.s and foot-pounds are just ar-
bitrary units for measuring work or energy. The internal energy
of a pound of air at 0° F., or 461° absolute temperature, is
found by simple arithmetic: 461 x .2375 = 109.4875 B.T.U.s;
109.5 B.T.U.s x 778 = 85,181.275 ft-lbs.

To relate internal energy to the production and use of com-
pressed air, I will reveal a fact that has not been published in

plain language in a compressed air textbook since 1930. The work
a compressor does in squishing air molecules together **all** becomes
heat. All of it.

But wait a minute! Doesn't that mean that isothermal com-
pression delivers no energy to the air it compresses? And that
adiabatically compressed air loses all the energy that the com-
pressor worked to instill in it, as soon as it has cooled in the
tank? Doesn't that mean that all compressors are 0% efficient?
Then what is pressure? Where does it come from?

The pressure left in the tank after the air has been beat
up by the compressor and then cooled is a concentrated form of
the same internal energy that the air contained before entering
the compressor. The compressed state of air is just a condition
that happens to have an advantageous relationship with the lower
pressure that the atmosphere happens to be at. Pressure is an
incidental advantage, resulting from solar-heated air molecules
zipping around and banging into each other in a squished-together
condition inside a metal tank. If the same number of molecules
were in the tank but were not zipping around and banging into
each other, no amount of squished-togetherness would put them in
a condition to do useful work. Internal energy is independent
of pressure. Air at atmospheric pressure contains lots of energy,
but is not in a condition that makes it useful for doing work.
The compressed air at 60° F. inside a tank just happened to get
trapped in there, with its internal energy concentrated into a
usable form. The hydroelectric energy derived from water at a
dam is not created by either the dam or the fact that the water
was flowing before it reached the dam; the energy is an inciden-
tal advantage of the condition that the water finds itself in:
trapped behind the dam. The dam doesn't put the water there, it
just concentrates water that's already elevated, as a lens focuses
dissipated rays into a point of light so hot it can start a fire.

Barring the conservation of compression heat that I sugges-
ted earlier in this chapter, the only reason compressors have an
efficiency greater than zero is that internal energy is still
trapped in the tank after all the work of the compressor has been
wasted. From this, one might guess that any air car could be at
least partially self-fueling if it 1) conserves compression heat;
2) introduces ambient heat; and 3) uses air expansively. This
might explain why so many inventors have been able to patent de-
signs for self-fueling air cars, when the patent office's policy
is to reject all claims for perpetual motion machines. This just
ain't perpetual motion; as George Heaton put it to me, the self-
fueling air car "**acts like** a perpetual motion machine."

The eminent physicist, Max Planck, didn't believe that it
would ever be possible to build a perpetual motion of the second
kind, that is, a machine that, without creating energy--which is
in direct violation of the first law of thermodynamics--still
would be able to concentrate unusable dissipated energy into a
usable form and then use it to do work, thus breaking the second
law of thermodynamics. Here are some of Plank's remarks, from
the seventh edition of his <u>Treatise on Thermodynamics</u> (1926):
"Such an engine could be used simultaneously as a motor and a
refrigerator [heat pump] without any waste of energy or material,
and would in any case be the most profitable engine ever made.
It would, it is true, not be equivalent to perpetual motion, for

it does not produce work from nothing, but from the heat, which
it draws from the reservoir. It would not, therefore, like per-
petual motion, contradict the principle of energy, but would,
nevertheless, possess for man the essential advantage of perpetual
motion, the supply of work without cost; for the inexhaustible
supply of heat in the earth, in the atmosphere, and in the sea,
would, like the oxygen of the atmosphere, be at everybody's im-
mediate disposal." The reservoir that Planck refers to is a
heat-reservoir. The machine in question refigerates a portion
of the heat-reservoir so that heat flows from the reservoir into
the colder portion, driving an engine in the process. The second
law states that it's impossible for this engine to both do work
on a load external to this system, and refrigerate the portion
of the reservoir into which heat must flow in order for the en-
gine to work.

   In order to evaluate the assertion that such a feat is im-
possible, consider the nature of refrigeration. A refrigerator
is a heat pump, that is, it moves heat out of air that is at one
energy level, and deposits the heat in air that is at a different
energy level. An example of pumping heat is removing ambient
heat from outside air in the dead of winter, concentrating it
into a usable form, and using it to heat a house. Since the heat
pump is only moving heat around, and not creating it, it doesn't
violate the first law of thermodynamics by pumping more energy,
in the form of heat, than the amount of electrical energy it uses
to do so. It's not unusual for a heat pump to have a Coefficient
of Performance (C.O.P.) of 3 or more, which means it provides
three times more useful energy than it consumes. Like the machine
Planck discussed, the heat pump only **seems** to violate the law;
the source of the energy it provides is solar. But heat pumps
don't run on the ambient heat of the reservoir they draw heat
from; if they did, then they'd be perpetual motion machines of
the second kind. It wouldn't be possible to run a heat pump on
its own heat and also derive extra work from the engine running
the heat pump's compressor, because exchanging heat is slow,
storing it is difficult, and using it to run an engine is inef-
ficient.

   Energy comes in grades, from "low-quality", dissipated
energy that isn't in a condition to do useful work, to "high-
quality", concentrated energy that is in a condition that makes
it able to do useful work. I've already used the example of
atmospheric pressure, which can't do useful work, and compressed
air, which due to its state of tension, or pressure, can do work
as it flows into the atmosphere. Gasoline is a very high-quality
source of energy, because it contains so much concentrated energy
for its weight and volume. Compressed air is much heavier and
space-consuming than gasoline, for the useable energy it contains,
but the lowest-quality type of energy source is heat. Try storing
heat in a simple metal tank, and it will disappear through the
walls of the tank. Insulate the tank, but don't forget to also
insulate every pipe and valve. Put too much heat in the tank,
and the tank melts. It requires a medium, such as air, to carry
it. Pressure as an energy carrier is much more convenient to
work with. It's easier to concentrate, easier to store, and ea-
sier to use than heat.

What is all this leading to? Compressors waste all their efforts to focus existing energy into a space whose energy content is proportionate to--but functionally independent of--the wasted energy. The work of compression is secondary; we can drop it as a factor and brainstorm backwards from the primary factor, compressed air, in a search for alternative, conservative means of compressing air. Heat pumps not only upgrade the abundant internal energy in atmosphere, as do compressors; they even make available more energy than they use. But they concentrate internal energy into heat, instead of the more useable pressure, and they use heat exchangers, not to mention freon. What we need is a heat pump with an overunity C.O.P. that turns the internal energy of atmosphere into compressed air instead of heat, and does so directly, making compressed air out of the same air molecules that are the source of the internal energy we want to upgrade. While thus eliminating the worst features of air compressors and heat pumps, we seek to combine their desirable features into a new combination of components that can compress ambient air without forcing it into a tank against its will, using conservative rather than dissipative processes.

It **is** possible to compress air without a mechanical pump, in fact without any moving parts. The jet pump uses moving air, or any fluid, to pump more air or other fluid from one place to another, raising the pumped air's pressure in the process. Jet pumps that move air from a region of subatmospheric pressure to the atmosphere, thus acting as vacuum pumps, are called "ejectors". Jet pumps that act as compressors, by moving air from a region of atmospheric pressure or higher, to a region of even higher pressure, are called "thermal compressors".

To explain how jet pumps work, I must expose still another of the hidden advantages of compressed air. All energy takes the form of either potential or kinetic energy, but not both at the same time. For example, the internal energy of an air molecule is kinetic--stored in its motion--when the molecule is zipping around. When it strikes another molecule, it stops, causing the other molecule to bounce away, and causing itself to ricochet off on a new trajectory. At the moment when the two molecules stop to bounce off each other, they aren't in motion, and all their kinetic energy has been converted to potential energy, a state of static tension that stores their energy as **wanting** to move. Then as they ricochet away from each other, the molecules' potential energy begins changing back into kinetic energy, until at maximum velocity their energy is all kinetic. Disregarding the individual molecules, a tank full of compressed air is in a state of tension, or pressure, which is a form of potential energy. But what if the mass of air inside the tank were to swirl around or vibrate back and forth? The static tension of potential energy would convert, to a greater or lesser degree depending on how fast the air was moving, into kinetic energy. The pressure would temporarily disappear to the same degree; the energy that had been pressure would exist as motion instead, until the air stopped moving. Then all the original pressure would be back again. This is a change of state, and is a thermodynamicaly reversible process, meaning that pressure and motion can trade places any number of times with no loss of energy.

This is not to say that any device using this reversible change of state is 100% efficient in its mechanical effect. The pumping efficiency of the jet pump is from 1% to 20% efficient, usually closer to 1%. The jet pump works on the principle of entrainment, that is the drawing in of a pumped fluid by the kinetic energy of the motive fluid. Compressed air enters a nozzle, which is a tube with a converging diameter. As the nozzle decreases in diameter, the air speeds up, thus converting its pressure into kinetic energy; this is known as the Bernoulli effect. The suction nozzle is correctly situated near the throat, or segment of smallest diameter, of the motive nozzle. The correct lengths and diameters of the nozzles maximizes the entrainment ratio of the jet pump, which is the ratio of the weight of the air entrained to the weight of the motive air used to do this pumping work. When the air from the two sources has mixed, the motive air is at a lower pressure than what it was at when it entered the jet pump, and the pressure of the pumped air is higher than what it started at; the two pressures have equalized. The mixture exits the jet pump through a diffuser, which is a larger diameter section that converts velocity into pressure again. Because only part of the energy of the motive air can be used for entraining secondary air, its pumping efficiency is very low.

But what happened to the rest of that energy? The first law of thermodynamics says it can't be destroyed; there were no moving parts for the energy to spend itself operating; there was no place for the air to leave the system, assuming there are no leaks; and no heat was produced or radiated, since the air-to-air jet pump is inherently self-cooling: the motive air cools as it expands and mixes with the entrained air that heats up as it is compressed. The "inefficiency" of the jet pump is a matter of context: what happens to the air that leaves the jet pump? The energy leaving the jet pump, a combination of the residual energy of the motive air and the upgraded energy of the entrained air, in many mundane applications is dumped into the system's environment, wasting all the residual energy contained in the jet pump's exhaust. But if the jet pump exhaust were used as a source of compressed or moving air, then the efficiency in its full regenerative context might be much higher than just the pumping efficiency of the jet pump taken out of the context in which it is to be used.

The best example of the phenomenon of the jet pump's low efficiency having nothing to do with the efficiency of the system that it's a part of, is the steam boiler injector, which was invented in 1858, and became standard equipment on steam cars and
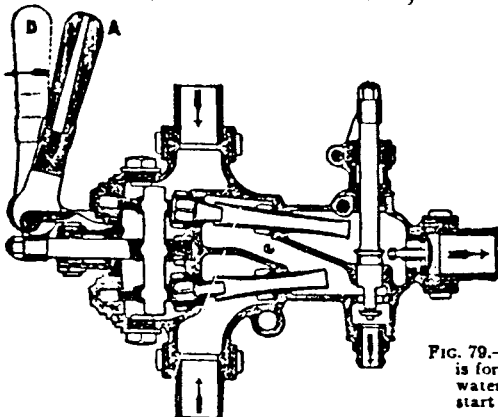
Fig. 79.—Sectional view of the Korting double tube injector. The lower tube is for lifting the water to the injector, and the upper tube for forcing the water in the boiler. A is the closed position of the operating handle. To start the injector, the handle is moved slowly in the direction D.
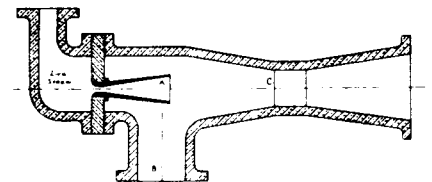
Fig. 1. Simple Jet Pump.

locomotives, and other applications. During the first years of
its use, the injector was little understood; some considered its
function a mystery, an anomaly, or just plain impossible. Until
Mr. Giffard of England introduced the injector, the only way to
get low pressure water into a high pressure boiler was to use
powerful pumps to increase the pressure of the water, forcing it
into the boiler against the resistance of the steam in the boiler.
The injector forces cold water into the boiler with no moving
parts and no losses. A pipe from the boiler supplies the motive
steam; the pressure of this steam doesn't have to be as high as
the pressure of the boiler. The steam and the water it entrains
enter the boiler through a check valve, which is a valve that al-
lows flow in one direction only, preventing steam from entering
the injector backwards. Like most jet pumps, the injector has a
low pumping efficiency: about 3%.

But unlike most jet pumps, the injector feeds the energy left
over from its motive supply, along with the entrained fluid, back
into the reservoir of energy that is the source of its motive
supply. The result of this arrangement is that the injector sys-
tem has an efficiency of 99-100%, despite the low pumping effi-
ciency of the injector itself. The only losses would be from

INJ.
EFF. = 3%

NET
EFF. = 100%

injector motive
100 psi

135 psi steam

135 psi water

injector

residual energy not used to pump H_2O
returns to tank fully conserved

cold H_2O
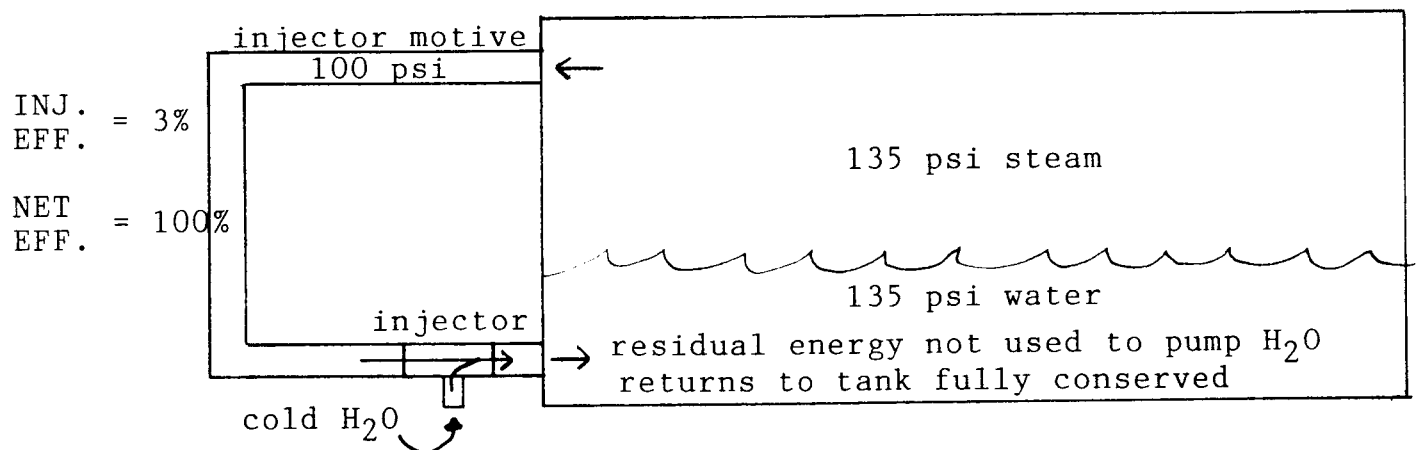
heat radiating through the body of the injector and through the
walls of the pipe that supplies it with steam. Here are some
comments from the experts:

"The principal advantages are that...practically none of
the energy of the steam used to operate it is wasted, as all
the energy in excess of that necessary to force the water into
the boiler is utilized in raising its temperature..." (Roper's
Catechism, 1899).

"There are practically no heat losses; all the steam used
to operate the injector is returned to the boiler and the only
heat loss is from radiation, which is very small...The efficiency
of the injector as boiler feeder is 100% less the trifling loss
due to radiation..." (Audel's Answers, 1943).

It has been found that whatever may be the pressure of air in the motor tanks beyond a certain very moderate excess above the working pressure, the additional power expended in compression cannot be made available in propulsion, but is lost in wire drawing the air through the reducing valve to a lower pressure. Consequently all the power expended to secure high pressures in the reservoirs serves only to increase the tank capacity and the length of run.

To avoid this loss, compound engines have been tried, but they are not only unsuited for small motors in consequence of complication, but they have failed to accomplish the object.

Another plan of utilizing the high pressure has been proposed by allowing it to escape through an injector, and thus forcing an additional volume of fresh air into the motor cylinders, reducing to that extent the draft upon the reservoir. It is not known that this plan has been tried, or, if tried, what has been the percentage of gain.

General Herman Haupt, C.E.
Street Railway Motors (1893)

"Some application of jet pumps are described, and it is pointed out that the definition of efficiency should be related to the particular application; for example as used in civil engineering the relevant efficiency can reach 60%." (BHRA Abstract #126, 1976; source abstracted: R. Silvester, 1961)

"Jet pumps find widespread application on account of their simplicity and convenience in operation, but are often not considered owing to the widely held opinion that their efficiency is very low. The aim of the paper is to show that this opinion is ill-founded....It is concluded that jet pump efficiency can be high (> 50%) if the residual energy of the primary flow is properly utilized and...that inadequate calculation methods which did not allow for the contribution made by the residual energy of the primary flow were to blame for the mistaken idea that jet pump efficiency is necessarily low." (BHRA Abstract #195, 1976; source abstracted: B. Temnov, 1967)

Although the boiler-feed injector would not work as-is to put low pressure air into a high pressure tank, the general principle it suggests is applicable to our search. The principle of entrainment takes the place of compressor and heat pump: it makes compressed air directly from atmosphere, thus upgrading the internal energy of atmosphere without heat exchangers or moving parts. The problem with jet pumps is that they require high pressure motive air, and lots of it, to entrain atmosphere. This in itself doesn't spell death for the idea of a self-fueling air car. It was first suggested in 1893 by one of the air car's greatest advocates, General Herman Haupt, a civil engineer who ran the railroads for President Lincoln during the Civil War. The question now is, can anything be done to use the principle of entrainment, with its advantage of no losses and no moving parts, more effectively than jet pumps do?

What can be done to the jet pump itself, to improve its entrainment ratio, so that less motive air would be required to operate it? The motive air normally enters the jet pump in a steady flow, but scientists have discovered that any jet pump works better if its motive fluid is pulsed, rather than steady. Pulsed-jet pumps entrain 400-700% more air than steady flow jet pumps. Pulsed jets organize into large toroidal (doughnut-shaped, like smoke rings) vortex rings, whereas steady jets quickly dissipate. Pulsating air organizes into waves of higher and lower pressure, in relation to the static pressure of the source that supplies the pulsed air. Could we get closer to our direct air-to-air energy upgrading system by looking at other devices that

use pulsating, oscillating, vibrating, or resonant fluids to entrain and upgrade lower pressure fluids?

In researching this question, I've found so many devices, including several self-fueling air car designs, that use pulsed fluids, that the phenomena surrounding pulsating air fit exactly in the holes in our general theory of self-fueling air cars. The rest of this book and its sequels are reserved for a detailed presentation of these research findings. The core concept is that pulsation of static air creates waves of compression and rarefaction in that air, which is such a unique effect that many unusual devices can be built on it, including many varieties of self-fueling pneumatic power plants whose source of energy is the upgraded internal energy of atmosphere.

Then what about the second law of thermodyamics? Do we just throw it out the window? It's important that we understand specifically what this law is meant to govern. Physicists are in agreement that the second law applies to the totality of energy systems, and not to local events. The law means that, in the universe as a whole, energy declines to a lower and lower state, dissipating and becoming more and more unavailable for use with each passing moment. This does not, and cannot, apply to local events; if it did, there would be no concentrations of energy anywhere, and all movement would be impossible. Everything that happens, especially life, proves that local bursts of energy are normal. As for the self-actuating heat-pump/engine condemned by Planck and others, I must further specify that the law applies to **closed** systems. If a self-fueling pneumatic power plant were situated in a closed, perfectly insulated room, then the air in the room would get colder and colder till the engine would no longer have a source of fuel. But the actual boundaries of the system we're dealing with must be taken into account. Our closed system consists of the entire atmosphere of the Earth with its continuous supply of solar radiation. Practically speaking, the heat reservoir from which our energy pump extracts fuel is not exhaustible, because of its magnitude in relation to the energy requirements of human civilization. I have no objection to the practical use of the second law, but to overgeneralize its effects goes way beyond the extent to which the law has actually been proven to apply. Any physicist can construct a conceptual model to "prove"--to himself and anyone who chooses to agree with him-- that an event is impossible. But to physically show that any event is impossible, is itself inviolably impossible. Or so it seems to me.

To demonstrate the concept that the second law doesn't have to apply to all local events, the pioneering physicist James Clerk Maxwell included in his 1870 thermodynamics textbook, Theory of Heat, a model of a way to get around the law. His model has come to be called "Maxwell's Demon", and has the distinction of being the only perpetual motion scheme that has attracted serious discussion by physicists and thermodynamicists. This debate has yet to die down; no sooner does one theorist publish his reasoning as to why Maxwell's Demon is impossible, than along comes the next theorist to contradict his predecessor and present his own opinion as to why Maxwell's Demon is impossible. Despite this ongoing

controversy, Maxwell's reputation as a major architect of modern
physics remains unscathed. Everyone from Einstein on down to
your local high school science teacher recognizes the enormity
of Maxwell's contributions to our understanding of the physical
world. It was Maxwell who discovered the existence of the elec-
tromagnetic spectrum. Not until his revolution in thinking did
we realize that light and all other forms of electrical and mag-
netic energy are the same thing at different energy levels. He
intuitively and mathematically predicted the discovery of what
were at that time unheard-of forms of energy, such as X-rays.
He was the first to thus use mathematics to explain realities that
had yet to be detected by direct observation. Could it be that
Maxwell's model of a way around the second law could be as accu-
rate and practical an intuitive leap as his discovery of the
electromagnetic spectrum turned out to be?

In Theory of Heat, Maxwell first agrees with the second law
that a self-actuating heat pump/engine in a closed room would be
impossible. Then he reminds us that, within a tank full of static
air, the individual molecules are by no means static. Not only
are the molecules in the tank all in motion, they're all moving
at different velocities. If the tank were divided into two parts
by a partition with a small hole in it, and a tiny being "whose
faculties are so sharpened that he can follow every molecule in
its course" were stationed at the partition, then this being, if
he were fast enough, could sort the molecules by their speed.
With the fast molecules sorted into one side of the tank and slow
molecules in the other, a heat differential would exist between
the two sides of the tank that could be used to operate an air
engine whose output would be many times greater than the work
expended by the being in sorting the molecules.

Maxwell's second law bypass, which others named Maxwell's
Demon, is a simple, direct, intuitive analogy. The being was
meant to be a symbol for unspecified hardware, but Maxwell's de-
tractors have focused on the being itself as if Maxwell had been
arguing the existence of the being. Nothing could be further from
Maxwell's intent. The 1951 "proof" that Maxwell's Demon is im-
possible was based on the conclusion that the being wouldn't be
able to see to sort molecules inside the dark tank. An article
published in Scientific American in 1987 contradicts the 1951
confutation and advances arguments so far removed from the prac-
tical questions Maxwell raised that I couldn't really tell you
what the article was about. It seems to be saying that the demon
is unemployable because he's computer-illiterate, but I confess
that I was unable to follow the convolutions of the writer's
thinking. Maxwell left us with a simply-stated riddle to solve,
and intuition tells me that the answer to the riddle will be, like
the answers to most clever riddles, so simple as to make fools of
us for having overlooked it for more than a century.

Any proof that Maxwell's Demon is possible would have to be
built from physical effects and processes demonstrable with actual
hardware. Rather than reducing the concept to testable specifics,
the detractors have taken Maxwell's analogy literally, and then
blindly involved themselves in abstract discussions of the sym-
bols and arbitrary terms within the analogy. They've interpreted
the molecule-sorting demon as a molecule-sorting demon; it would
be more accurate to interpret the analogy as a fast, easy way

(not demon) to continuously organize (not necessarily sort) units (not necessarily individual molecules) of air into zones of unequal energy concentration. This simple, accurate interpretation of the core concepts behind Maxwell's analogy leads directly to the sound wave as the physical manifestation of the symbolic demon. The sound wave is a disturbance moving through the air at 750 miles an hour. The wave consists of alternating zones of compression and rarefaction which are larger than individual molecules but smaller than an air tank. The power of the sound wave can be many times greater than the power used to make the wave, because of resonance.

Every solid, liquid, or gaseous body has its own innate resonant frequency, which is the frequency at which it **wants** to vibrate. Because bridges have resonant frequencies, soldiers marching across a bridge must break stride; if they were to march rhythmically at a frequency coinciding with the bridge's resonant frequency, their marching could trigger an earthquake, destroying the whole bridge. You can find the resonant frequency of an air tank with one open end by singing or humming near the open end. Some notes will dissipate in the air around you, but other notes will be augmented by the tank, which will sing along with you when you hit notes coinciding with the resonant frequency of the air column it contains. By triggering resonance within a tank full of compressed air and within the pipes entering and leaving the tank, it is possible to inject more atmosphere into the tank, without compressing it to get it in, than is needed to replace the compressed air leaving the tank to power this whole process and do external work besides.

More power to us all.

Chapter Three—STATE-OF-THE-ART PEACE SINES

You wouldn't have believed it if they'd told you in school, so they didn't tell you. Evidence from scientific literature that suggests we can achieve the impossible by making the right waves, in the right place, at the right time.

Notes on a Landmark Research Trip, 5/24/88

Running through the vast and varied scientific literature on ongoing research into moving fluids with waves, there's a common thread of newness, unfamiliarity and discovery. Statements are often made like, such and such can't be accounted for theoretically so we had to do a bunch of experiments to figure out what would happen under certain limited conditions that we could test.

An article I have only the abstract for—"Production of a vacuum in an air tank by means of a steam jet." Minimum steam ejector motive pressure should be 120 psi for high vacuum with reasonable steam-air ratio. Best results obtained by using a "steam jet which had been over-expanded in the nozzle, resulting in axially periodic variation in cross-sectional area and pressure." This was determined by a detailed study of the expansion waves under different conditions.

A pump comprising an oscillating loop and two check valves...

Englewood, CO—The relative motion between this pump's tubular housing and the fluid contained in that housing creates a pumping action free of pistons or impellers. The housing, a fluid-filled loop, oscillates in the general direction of flow. "Inertia" carries fluid to the outlet.

Manufactured by Horst Dynamics Inc., the pump comprises the housing, a drive motor, and connecting rod. The latter, eccentrically positioned on the motor flywheel and fixed to the housing's lower half, generates the oscillating motion.

The housing comprises an axially aligned inlet and outlet, right-left flow paths, and two check valves—one for each flow path. The assembly pivots around the centerline of the inlet/outlet ports.

In operation, the connecting rod moves the bottom portion of the housing back and forth at 1800 cycles per minute. When the housing accelerates clockwise, the column of fluid in the loop's left half is accelerated with the loop outlet. When the housing changes direction and moves counterclockwise, fluid in the right half is accelerated.

Pressure fluctuations just downstream of the valves open and close the two check valves. The valves, in turn, provide free inlet flow to each half of the loop.

TUBULAR HOUSING

INLET

MOTOR FLYWHEEL

OUTLET

CHECK VALVE

CHECK VALVE   CONNECTING ROD

112/Design News/7-16-84

Pump components. Unit pivots about centerline of inlet port. Connecting rod, eccentrically positioned on flywheel, transmits oscillating motion. When loop accelerates clockwise, fluid in left half accelerates. When loop decelerates, inertia pumps fluid to outlet. Housing's right half operates in the same manner.
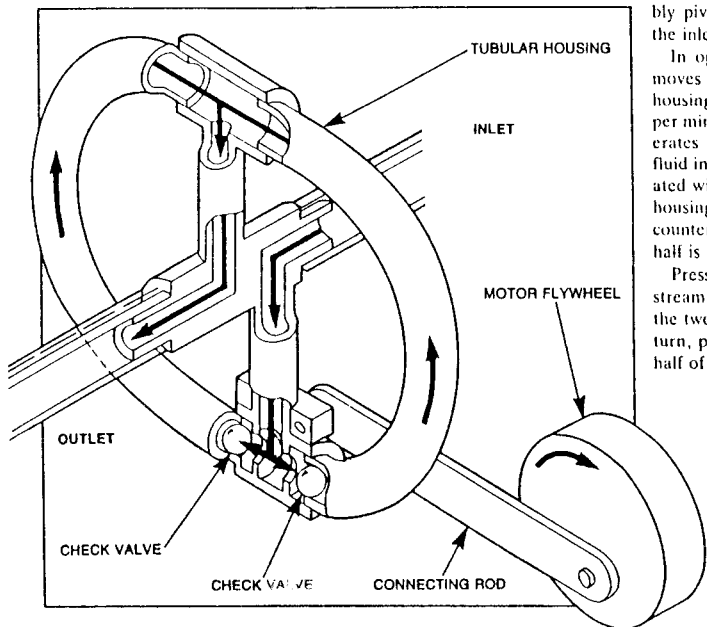
OSCILLATING 'LOOP' PUMPS MOST FLUIDS

Unit can be throttled to zero, run dry

David J. Bak, East Coast Editor

"The only significant losses are the pressure drop across the check valves and the energy required to oscillate the housing." "Self-priming to 8 ft." "Pumps most fluids." "Inherently efficient." Wilbur J. Shaffer, Horst Dynamics Inc., 3960 S. Kalamath, Englewood, CO 80110, 303/761-6309. The pump can be "throttled to zero and run dry."

A cylindrical resonator with radial motive air intake ports; generates shock waves (internally generated traveling shock waves) with maximum pressure nearly three times motive pressure, and high temperatures. Optimum motive jet pressure ratio 3.76. Temperatures not measured in this experiment, but similar measurements with a simple Hartmann resonance tube show end wall temperatures of 400* C. with nitrogen and 1200* C. with helium.

underexpanded jet — alternating inflow/outflow (HIGH TEMP. HIGH TEMP.)
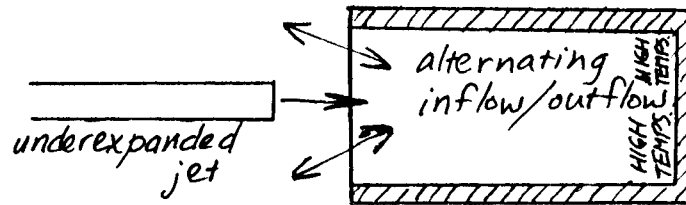
Hartmann tube

There are whole journals and symposiums devoted to shock waves and shock tube research.

pressure source — open end — diaphragm
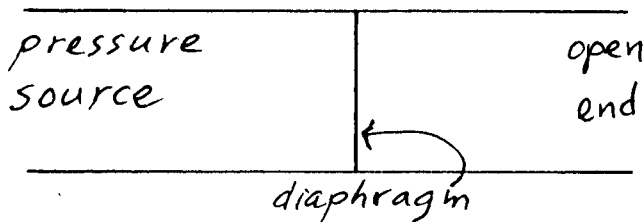
shock tube--pressure side is slowly pressurized till diaphragm bursts. Sudden discharge creates the shock wave.

Since oil hammer (water hammer in hydraulic oil) generates a higher pressure than that supplied to the pipeline, someone decided to make a pressure intensifier by generating a continuous oil hammer. Only the high pressure oil leaves during the open cycle of a solenoid-operated open/shut valve in the end of the pipe. The continuous opening and closing produces the wave hammer. Maximum pressures obtained are over six times the supply pressure.

Subatmospheric pressures (partial vacuums, suction spaces) appear in the oil hammer cycle.
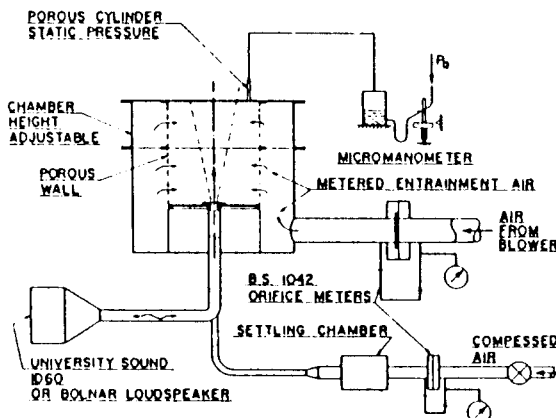
Fig. 1   Cross section through entrainment chamber

A jet can be caused to pulse by coupling its supply pipe to a source of acoustic excitation (loudspeaker). Entrainment rate of the pulsed jet was almost six times higher than the steady jet. The experiment was set up using a blower to supply entrainment air. A possible explanation for the consistently higher entrainment capacity of a pulsed jet is that the pulsed jet organizes itself into large structures such as ring vortices. An example of the ring vortex is the smoke ring.

Reciprocating jet pumps work on a different cycle than pulsating jet pumps or pulsejet pumps, but the end result of somehow achieving pulsating flow are predictably superior to steady flow jet pumps. Reciprocating jet pumps have a blow stroke and a suck stroke, each through separate jets, and the difference in dynamics between the two types of jet action in the entrained flow generatesa positive one-way steady flow, and raises the pressure of the pumped flow. Measured efficiencies for pumping are up to 32%. The boiler feed injector, which is 99-100% efficient in context, is less than 3% efficient as a pump.

Pulsejet pumps, according to one source, can have a pumping efficiency of 60-80%. They were widely used in steam engines. One application was called the "Kylchap exhaust" or "Kylchap Pulse-jet Aspirator."

STEADY-FLOW EJECTOR

PULSATING-FLOW EJECTOR

(a)

(b)
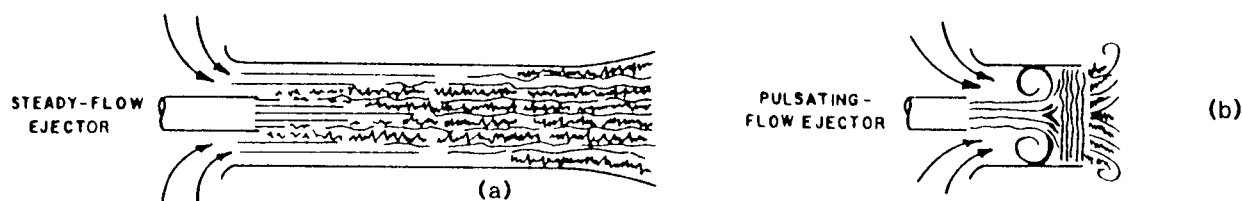
Fig. 1 - Schematics of steady-flow and non-steady flow ejectors [6].

There are plans and kits available for pulsejets that are used on one-man helicopters. On a helicopter the jet goes directly on the rotor tips to drive the rotor without the usual engine and shaft. One reference (1945) states that pulsejets were being considered for automotive and marine propulsion.

Pulsejet operation is not controlled by the check valves but by the length of the tube, etc. Resonance is the working principle. The check valves are actuated automatically by pressure reversals in the tube. The sudden evacuation of the tube and high velocities create subatmospheric pressures due to the Kadenacy effect. At low speeds the pulsejet sucks as much air in through the tailpipe on the intake "stroke" as it takes in through the check valves at the same time. So Kadenacy's depression works in all directions, as pressure does. The air entering backwards through the pulsejet's tailpipe robs it of 20-40% of its maximum thrust at 300-400 mph. This defect doesn't apply to the case of the Neal equalizer, as it would be a limitation to jet thrust only and not to available energy in a tank.

The Kadenacy effect was discovered by Huygens in 1670. The Kadenacy effect is how it's termed in relation to piston engines. The pulsejet is directly related to piston engines, not jets. One article states that a propeller run off the pulsejet exhaust would make a far better power plant than any turbojet. This is analogous to an air motor run off Neal's equalizer tank.

Air induction and compression by pulsejet is by means of dynamic inertia. The pulsejet works like an organ pipe, in the way that the standing wave inside the tube organizes the air into high and low pressure zones.

I learned a new word: pressure exchanger. A pressure exchanger transfers energy directly from fluid to fluid, by direct contact between the two fluids of different pressure. There are no intermediary devices such as pistons, compressors or turbines. Direct pressure exchange can be effected by means of three processes known to the author of this article: 1) SSPE steady flow transfer by mixing, 2) DPE unsteady flow transfer by means of pressure wave processes, and 3) crypto-steady flow transfer by means of moving pressure fields that are generated by the collision of two fluid flows.

The first commercial use of the SSPE (Semi-static Pressure Exchanger) was as a heat pump put out by Brown Boveri in Switzerland in 1943, and based on the patents of A.F. Lebre, British Patent # 290 669, 1928. A rotating member divided into cells open on the sides passes ports containing high and low pressure fluid, adding the two fluids together by pressure equalization and increasing the pressure of the low pressure input.

The DPE (Dynamic Pressure Exchanger) is based on the concept of the SSPE, but the expansion and compression processes take place by means of pressure wave effects. The only pressure exchanger being marketed that I know of is a DPE called the Comprex Supercharger for diesel engines. It's sold as a stock part on a particular engine.

Diagrammatic layout of pressure exchanger (DPE)
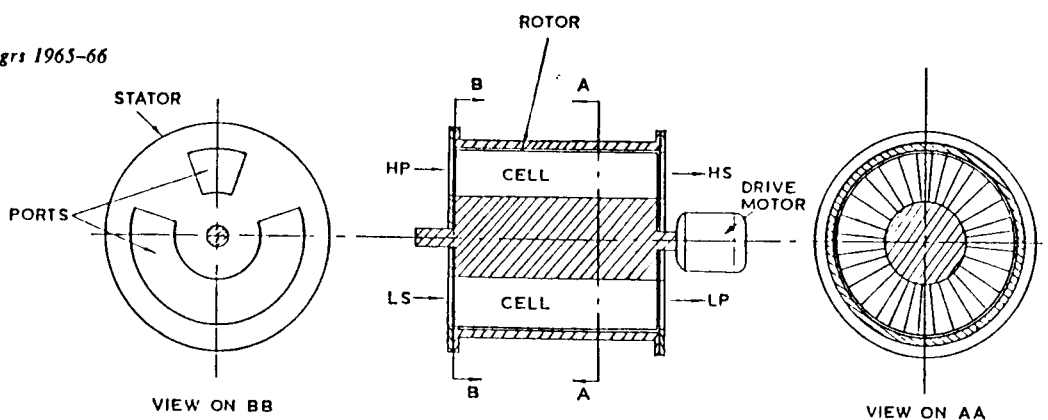
A cell full of high pressure fluid passes the low pressure port and suddenly discharges. The Kadenacy effect creates a depression or subatmospheric pressure that causes the cell to fill with low pressure fluid again before it passes the low pressure port. Then the cell passes the high pressure port and the low pressure contents are augmented and evacuated by the high pressure flow, this evacuation inducing the next batch of air. The DPE works better than the SSPE because of wave processes, and the wave processes have an advantageous effect because of the Kadenacy effect. So the pulsejet concept is still coming through. The Kadenacy effect makes plain old unpressurized 0 psi atmosphere a pumping power in itself, much as the heat pump converts totally dissipated ambient heat into an active heat source. In the DPE, when the cell passes the low pressure port and is suddenly blocked, a pressure wave forms in the low pressure fluid that makes the low pressure fluid ready to evacuate before the blast of high pressure air blows it out. Then the depression makes the intake end of the process happen by itself.

CELL-EMPTYING · CELL-FILLING · HIGH-PRESSURE SCAVENGE · LOW-PRESSURE SCAVENGE

HIGH-PRESSURE SCAVENGE
FUNDAMENTALLY EQUIVALENT
TO A MINIMUM NUMBER OF
ONE CELL-EMPTYING PROCESS
PLUS ONE CELL-FILLING
PROCESS

LOW-PRESSURE SCAVENGE
FUNDAMENTALLY EQUIVALENT
TO A MINIMUM NUMBER OF
TWO CELL-EMPTYING
PROCESSES PLUS ONE
CELL-FILLING PROCESS

— — — — rarefaction wave.
———·——— compression wave.
·········· interface.
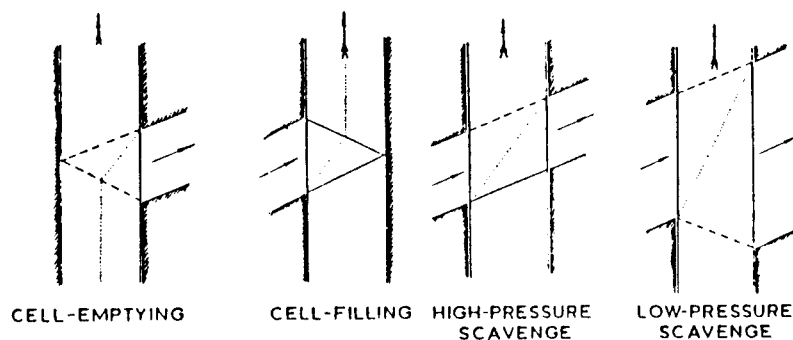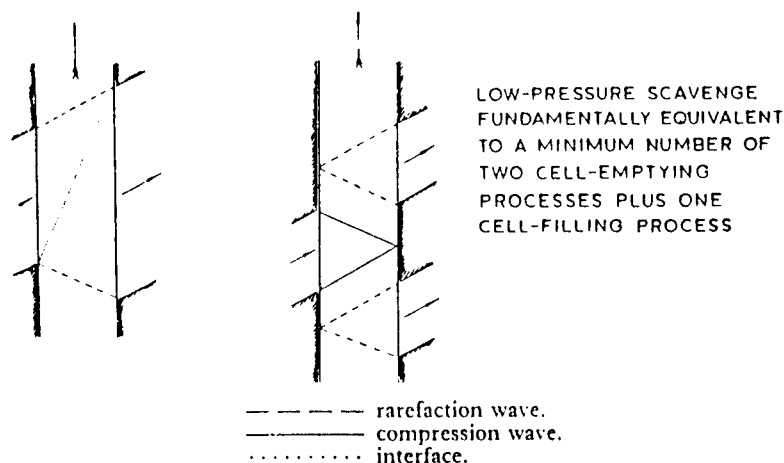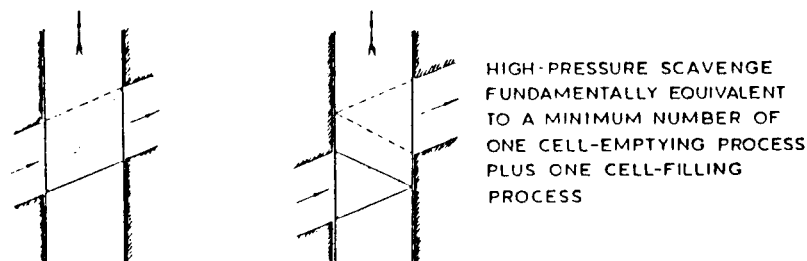
The fundamental wave processes simplified

There's even a DPE called an equalizer. "The equalizer/divider is one example in which the DPE acts purely as a pressure interchanger. In the so-called equalizer, a high-pressure gas stream is expanded to the same pressure level as that to which a low-pressure stream of gas is compressed, the two exhaust streams being then led to a common duct." The equalizer can replace the ejector or jet pump. The maximum isentropic product efficiency for the ejector is 21% and for the equalizer about 75%. The divider is a DPE in which one fluid stream is split into a high output and a low output, doing with pressure what the vortex tube does with heat. The vortex tube takes a single stream of compressed air and splits it into a hot output and a cold output. It has a dissipative effect, while the divider puts out mechanical energy (pressure) instead of heat and works by a nondissipative process.

Equalizers and dividers can be compounded for greater pressure ratios.

Because pressure equalization is accompanied by temperature equalization, DPE's are self-cooling.

The Pearson wave rotor engine in the mid-'50's could operate over a relatively wide range of off-design conditions, produced 5 to 35 horsepower at the output shaft. It was a wave rotor (DPE) with the blades or tube walls bent somewhat at the ends. Part of a revolution was devoted to compressing the intake air while the rest of the cycle used the expansion of the exhausting gas (heated by an external combustor) to extract shaft work.

Like Maxwell's Demon, "The transient response of the wave rotor is extremely fast because the wave patterns internal to the device can readjust on timescales like the acoustic transit time along the length of the rotor, e.g., on the order of a millisecond." Maxwell's Demon moves at the speed of sound.

SYNCHRONOUS ALTERNATING LIQUID CURRENT MOTOR.

UNITED STATES PATENT 1,432,673 Patented Oct. 17, 1922.

GEORGE CONSTANTINESCO, OF WEYBRIDGE, ENGLAND, ASSIGNOR TO WALTER HADDON, OF LONDON, ENGLAND.

APPLICATION FILED AUG. 25, 1921.

1,432,673.   Patented Oct. 17, 1922.
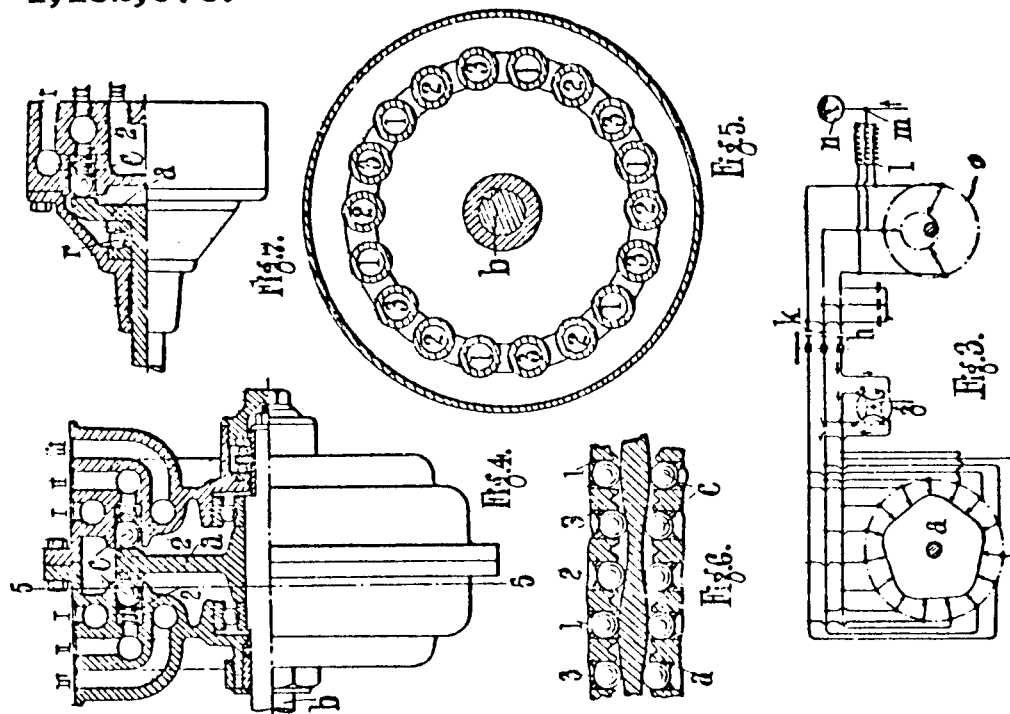
US Patents # 1,334,280-1,334,291 inclusive are all granted to G. Constantinesco for various uses of alternating liquid currents. #1,432,672 and #1,432,673 (Oct. 17, 1922) are to the same inventor for alternating liquid current motors. In particular #1,334,290 is for liquid wave transmission of power.

Cryptosteady pressure exchangers, of which one is the pulsejet pump,

demonstrate a uniquely nondissipative way to generate the already nondissipative process of pressure exchange. The rotary jet is another cryptosteady pressure exchanger. A hollow rotor extends into a cylindrical chamber, and motive fluid escapes through jets in the outwardly helical rotor. The jets cause the rotor to spin and the shape and motion of the rotor define fluid pseudoblades that are boundaries where the primary and secondary fluids exchange energy by direct contact, one half of each pseudoblade acting as a propeller (fan, compressor) and the other half acting as a turbine (motor) with the two performing the function of an air motor running a compressor without the intermediate processes, parts and losses, by bearing directly on each other.

1918—Seattle's Maple Leaf pumping station obtains over one million gallons of water daily using two 12" ram pumps. The hydraulic rams are powered by a 50 foot head to pump water back up a 131 foot head, at almost no cost—efficiency is from 85-91% Other sources give the ram pump an efficiency of up to 90%.

That's the main thrust of it——————
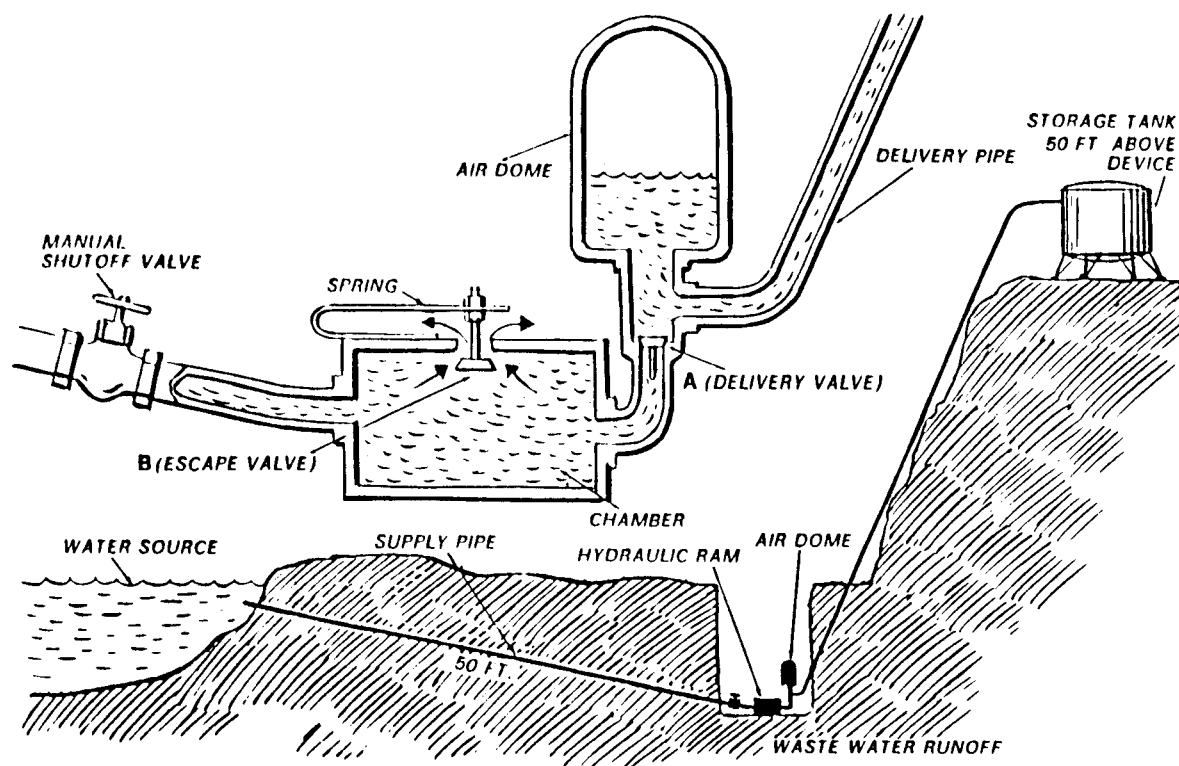
The How and Why of Mechanical
Movements by Harry S. Walton   Hydraulic ram.
© 1968 E.P. Dutton & Co., Inc.

Compressed Air Power Generating System
Baruch and Isaac Leibow
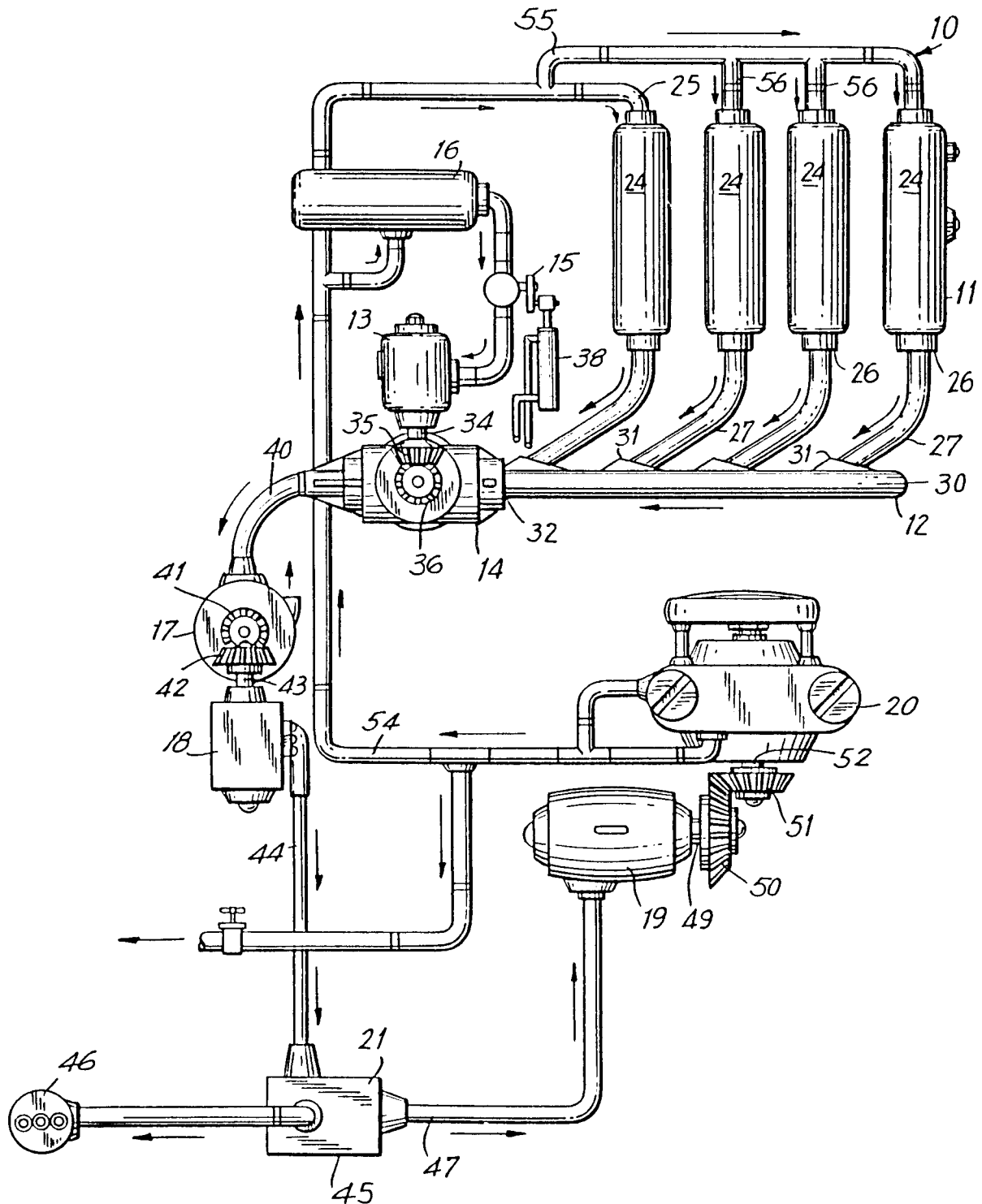
Chapter Four--"THE REST IS TOP SECRET"

The U.S. Patent Office doesn't grant patents for perpetual motion
concepts, but it does grant patents to inventors on self-fueling
air cars. Excerpts from patent papers, newspaper and magazine
articles, and the author's comments, on some of the air car designs
that seem to invoke Maxwell's Demon.

Baruch and Isaac Leibow

The Leibow system uses a "sprayer" to deliver a pulsating air supply
to the turbine air motor, which to my knowledge is an unusual way to supply
a turbine. This suggests that the purpose of the sprayer is to set up
resonance in the manifold that discharges to supply the turbine. This
guess is backed up by the presence of a named and numbered "closed end,"
the end of the straight manifold opposite to and upstream of the discharge
sprayer. Due to the Kadenacy effect, each discharge pulse to the turbine
would create a momentary depression or anomalous subatmospheric pressure
throughout the manifold or in parts of it or in waves moving through it.
The pipes entering the manifold from each of the four tanks that supply
the manifold join the manifold at an angle, like the entrainment nozzle
of a suction dredge (jet pump), and reminiscent of George Heaton's remarks
about "putting the air in at an angle or something" to get low pressure
air into a high pressure tank.

The four tanks are maintained at a relatively constant pressure, like
Neal's equalizer tank. The tanks are used at "about 12 atmospheres" or
about 160 psi; Neal's equalizer tank is supposed to be used at 200 psi.
Compressed air at about 180 psi is used to start pulsejet engines. A
compressor run by the system supplies Leibow's tanks with air higher in
pressure (the patent says) than the 160 psi in the tanks. Neal's design
allows for coupling the equalizer tank with an outside pressure source
to "augment" the incoming low pressure air, to keep the tank at a constant
pressure as Leibow's compressor is supposed to do. The pressure in Leibow's
tanks isn't really constant but drains much more slowly than would be the
case if there were no replenishment. The Leibow's "Compressed Air Power
Generating System" generates electricity continuously and operates for
extended periods. The Neal unit generates extra compressed air continuously
for "actuating additional equipment," and according to my sources, never
needs a fillup.

Leibow's compressor is a "positive displacement blower", which means
it's like an automotive supercharger, either a Roots blower or a rotary
vane compressor. This class of compressor is analogous to the Wankel en-
gine, being a rotary piston. Superchargers always deliver large volumes
of low pressure air, and to my knowledge are incapable of doing the oppo-
site. Leibow's patent says their positive displacement blower is putting
small volumes of high pressure air into a low pressure (160 psi) tank.
That's not what positive displacement blowers do; they do the opposite.

Lee Rogers' 1987 supercharger patent comes to mind. It's for an axial
blower that supercharges a radial blower, with the unit comprising a
two-stage supercharger. And in my own working model of Neal's compression
unit I found it necessary to use a rotary vane compressor supercharged by

a centrifugal blower. But in no case does a rotary vane compressor or Roots blower deliver air above 15-30 psi. And the last time I tried to adapt a blower to deliver only a little air, it didn't deliver anything at all.

I don't know what the Leibows had in mind, but I have little doubt that their positive displacement blower is so named for a reason. I wouldn't be surprised if this is a disguised version of putting low pressure air into a high pressure (160 psi) tank, by tapping the node points of resonating air. The patent states that partial replenishment of the air in the tanks by the compressor is what makes a given quantity of air last substantially longer than if it were just being used to run a motor. This could hardly be the case if only a small volume of air were being supplied by the compressor. It could be that the Israeli inventors hired a skeptical patent lawyer who changed the wording, thinking they'd made a mistake in English usage. Or the patent office might have prohibited them from saying that they were putting large volumes of low pressure air into a high pressure tank.

At any rate, the Leibow patent is unusual in its clarity and simplicity--till it gets confusing.

Leroy Rogers

Once again, the key to possibly linking an inventor's secret to Neal's patented pulsejet-type equalizer is in the discrepancies between various things that have been said (or conspicuously not said) about the design. I support an inventor's right to do whatever he needs to keep his secret a secret, even if it means his description of his own design is going to be interwoven with clever omissions. I also like to think that an independent researcher like myself has the right to try to figure out someone else's secret.

While I'm off on this tangent, I'd like to invite all the air car inventors and researchers in the world to come have a big meeting together. Then instead of each inventor individually complaining about harrassment, lack of funding, and still having bugs in the system, the inventors together would have safety in numbers, enough fund-drawing capacity to design and build any number of air cars, and an incredible brainbank from which to draw new perspectives on technical problems.

The discrepancies that clued me in to the connection between Rogers and Maxwell's Demon have to do with what the patent says about the design compared to what a witness says in a magazine interview. The witness, Glynn Wiggins, operated the car. Having just earned his doctorate from the University of Tennessee in auto mechanics instruction, I presume that his opinion counts. Glynn Wiggins, who one of my correspondents has interviewed, says Rogers' claims are truthful. Rogers himself has admitted in a published interview that no one, including his wife, knows his key secret. I suspect this secret could be Maxwell's Demon.

The confusion here looks much like the confusion I pointed out in the Leibow patent. The patent calls the high pressure supply compressor a compressor but calls its task the generation of the tank's working pressure: 500-600 psi. The term isn't "compression of air", but "generation of the pressure desired by the tank," and "supplying the tank with compressed air." I think these aren't so much descriptions of specific

processes but more like ways to talk about getting air into a tank without referring to the means used for getting it in.

The Rogers patent describes a system for pulsing short bursts of 500-600 psi air to each engine cylinder during its power stroke. Glynn Wiggins says the engine runs on only 80 psi. The whole truth may be a combination of the explanations put forth by the Rogers patent and the Wiggins interview. The engine is 4-cycle, having a stroke for intake of ambient air and then a stroke for compressing that air. Then, for a power stroke, a pulse of 500 psi air that immediately equalizes with the hot just-compressed air to arrive at an engine working pressure of, I'd guess, about 80 psi. Wiggins also says the "blower" (which the patent calls a compressor, with no further description) only recaptures 1/20th of the engine's exhaust--"in the storage tanks." The tanks seem to need a constant pressure, and the recapturing of compressed air is again not being called compression, and it seems the tank has an active role in the recapturing. And 19/20ths of the air the engine uses is ambient air. Rogers' 4-cycle air engine is an equalizer, adiabatic compressor, air engine and heat pump combined. The injection of 500 psi air to raise the pressure of the just-compressed ambient air is an equalizer or pressure exchanger process, that is, compression by mixing with existing pressure rather than compression by squishing molecules together with a machine. The exhaust

U.S. Patent Office
Official Gazette
September 15, 1987

4,693,669
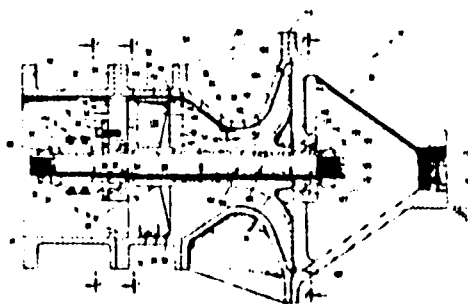SUPERCHARGER FOR AUTOMOBILE ENGINES
Leroy K. Rogers, Sr., Rte. 13, P.O. Box 815-DD, Briarcliff Rd., Fort Myers, Fla. 33908
Filed Mar. 29, 1985, Ser. No. 717,652
Int. Cl.⁴ F04D 17/02, 29/40
U.S. Cl. 415—143   7 Claims

3 A supercharger comprising
a housing having a longitudinal axis and being constructed from sections, which sections are connected in end-to-end relationship, said sections including a front housing section defining an axially directed inlet, an axial compressor duct section for housing an axial compressor, a rear housing section downstream of said axial compressor duct section and an exhaust section having a hollow, highly convergent, frustoconical, exhaust cone portion downstream of said rear housing section, a downstream portion of said rear housing section defining a cylindrical, axially directed inlet for a radial compressor, a casing for a radial compressor, and a substantially radially directed outlet for

a radial compressor, said rear housing section further defining a highly convergent, hollow, frustoconical transition duct between a downstream end of said axial compressor duct section and said radial compressor inlet, said rear housing section having interior surfaces for defining a flow deflector, which flow deflector receives the output of said outlet for a radial compressor, which flow deflector provides a smooth surface transition from said rear housing section into said exhaust section, said exhaust cone portion defining at a downstream end a coaxial outlet, said housing further including at least two bearing supports affixable within said housing according to predetermined locations along said longitudinal axis of th housing, said bearing mounts rotatably supporting a compressor shaft, which compressor shaft is positioned along said longitudinal axis;
bearing assemblies removably implaced in said bearing supports, said bearing assemblies receiving said compresso shaft;
an axial compressor located within said axial compresso duct and secured to said shaft to be rotatable therewith said axial compressor drawing a flow from said inlet of th front housing section and imparting an initial compressior to said flow;
a radial compressor located within said casing and secured to said shaft to be rotatable therewith, said casing being ir a substantially sealing relationship with said radial compressor, said radial compressor including a hub, a first set of blades extending radially from said hub and having leading edges at an intake region of said radial compressor and a second set of blades extending radially from said hub and having leading edges downstream of said intake region, said radial compressor further compressing said flow;
at least one pulley wheel secured to said compressor shaft and adapted to receive drive belts;
spacers fitted upon said compressor shaft for axially positioning said axial compressor and said radial compressor relative to each other; and
means for securing said compressor shaft against axial displacement;
wherein said transition duct favorably directs the output of the axial compressor into said inlet of the radial compressor and said exhaust cone section encloses sufficient volume to moderate the output of said radial compressor

pressure from the engine is 25 psi. The portion of this exhaust air that must be recaptured in the tank (1/20th) is the same amount that the tank supplied. This design seems to be making use of the weight (and possibly the pressure, using the Kadenacy effect) of ambient air, not to mention ambient heat and adiabatic compression heat.

The 1/20th of the exhaust that must be supplied to the tank enters the compressor (blower) at 25 psi and can't possibly be raised back to 500-600 psi with anything called a blower.

Another clue is that the compressor is to be fitted with a gearbox that the driver can use to increase the relative speed of the compressor when the speed of the car increases, so as to continue being able to "generate the 500-600 psi that's preferable in the tank." But this compressor which the patent doesn't classify as to type is called a blower by Wiggins, and would instead have to be a 2- or 3-stage piston-type compressor to compress air to 500-600 psi efficiently. And to get a higher pressure out of a given piston-type air compressor, you have to decrease its speed to facilitate cooling. But if you increase the running speed of a blower, you increase its low pressure volume, which I think is what Rogers uses to generate the 500-600 psi preferably in the tank.

Like the Neal/Heaton concept, to keep a tank full without squishing air together you must effect an energy exchange in which existing tank pressure is combined with existing ambient air weight to make free fuel. My question for Lee Rogers would be, "How do you keep a 600 psi tank full with a blower?"

Steve Hudspeth and John Lunsford

Hudspeth and Lunsford's patent lawyer called their air amplifier an air pulsing system. While the term "pulse" is used several times, the significance of pulsing is not addressed—an interesting omission. The purpose of pulsing here might be to pulsate the jet pump action that gets

AIR PULSING SYSTEM

Inventors: Steve A. Hudspeth; John B. Lunsford.
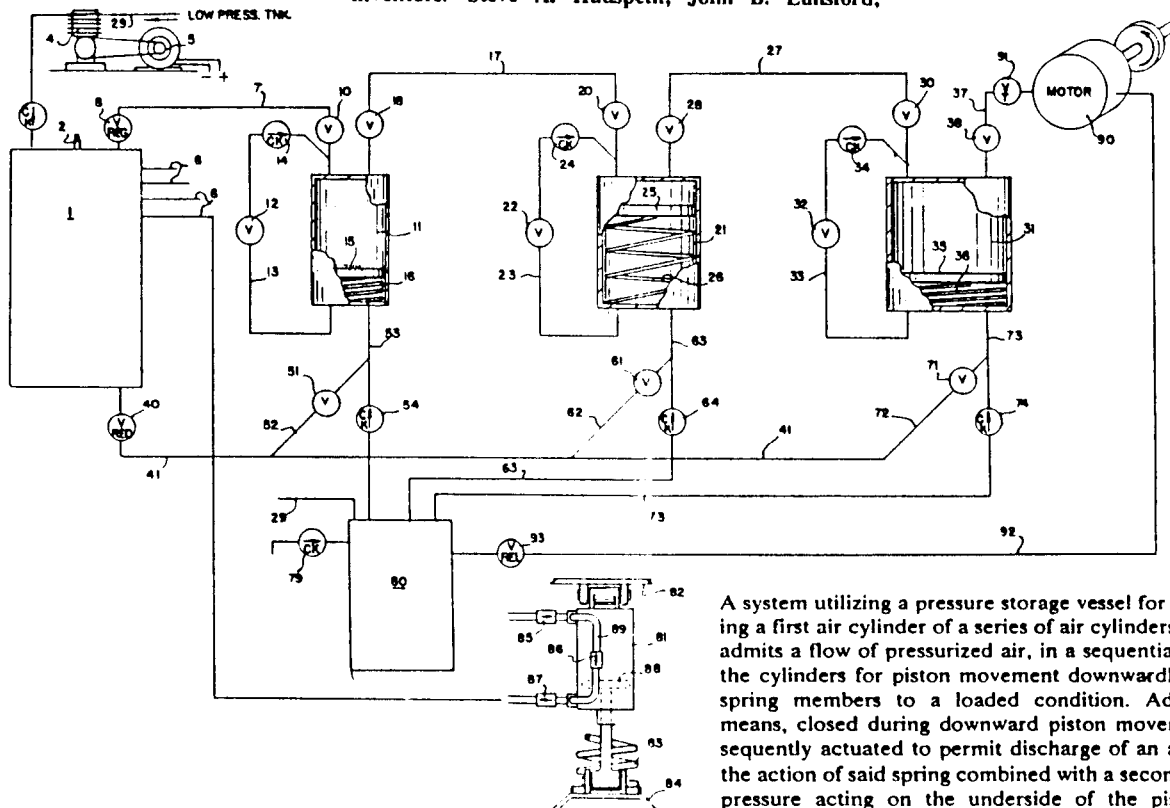
A system utilizing a pressure storage vessel for initially charging a first air cylinder of a series of air cylinders. Valve means admits a flow of pressurized air, in a sequential manner, into the cylinders for piston movement downwardly to compress spring members to a loaded condition. Additional valve means, closed during downward piston movement, are subsequently actuated to permit discharge of an air impulse, by the action of said spring combined with a second source of air pressure acting on the underside of the piston. The last cylinder of the series is operable to impart a force to a media for the operation of a motor for powering a vehicle.

the engine exhaust back into the high pressure side, ready to go back
into the engine, without squishing it in a compressor.

The invention employs oscillators or pistons without shafts that move
back and forth in cylinders. The pistons separate the high and low side
within the three cylinders of the compressed air amplifier. The piston is
assisted toward the center of the cylinder length by a spring on the
low pressure side. The piston is a moving wall in a tank, sounding a lot
like a prop in another variation on the basic theme of Maxwell's Demon.
And there could be some use of the Kadenacy effect.

There's more to be said about Hudspeth and Lunsford's air car, but
first there's more to be understood. Basically it's a pressure exchanger
that provides air for a motor with an onboard compressor playing only an
incidental role, like the compressors in other designs in this section.
The normally wasted highest pressures--which the car must carry to get it
over long, heavy loads--and the normally wasted lowest pressure--that of
the engine's exhaust--are mixed together by the amplifier/pulsing system
to effect a pressure exchange from the too-high tank pressure to the
too-low exhaust pressure, arriving at a medium pressure that's just right
for the engine. Provision is made for entry of atmosphere through a check
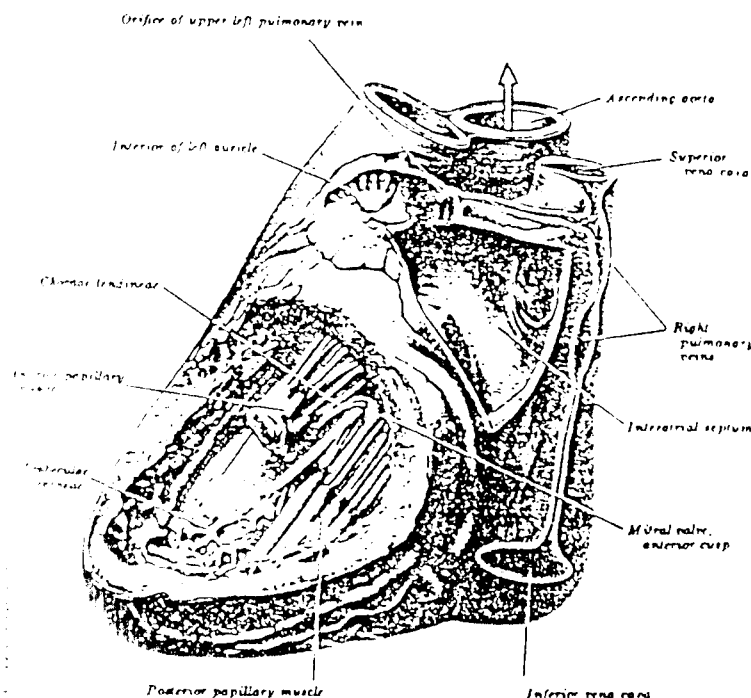valve into a low pressure tank, in case a partial vacuum were to exist
within the tank.Why there'd be a vacuum inside a tank where all the
pressurized motor exhaust is captured, the patent doesn't say, another
interesting omission. But the drawing invites speculation--a super-
charger could get a lot of ambient air into a tank full of pulsating
compressed air.

Hudspeth and Lunsford's patent does mention the fact that the highest
pressure found in pulsating air is higher than the pressure the air would
be if it weren't moving.

Bill Truitt

When I asked Bill Truitt if the eight to twelve small air pumps on
his air car were used to compress air to a high pressure to get it into
the high pressure tank, he answered a little quickly, I thought, as if
he been waiting for questions like that. "It's all high pressure," he
said. It sounded like he was changing the subject.

Truitt's secret lies in the workings of his "leakproof valve"
which is the classified property of the U.S. Army and NASA. All
Truitt could tell me about the valve is that it works like a heart.

Orifice of upper left pulmonary vein

Ascending aorta

Interior of left auricle

Superior vena cava

Chordae tendineae

Right pulmonary veins

Interatrial septum

Mitral valve, anterior cusp

Posterior papillary muscle

Inferior vena cava

New Scientist, July 8, 1982
"The Sounds of Muscles in Action"
by Gerald Oster, pp. 102-104

Indeed, the loudest component of the heart beat, the
so-called first heart sound, is a 25 cycle per second sound
that lasts about one seventh of a second and pulsed,
typically, at roughly once a second (more correctly 72
beats per minute). The first heart sound occurs at the time
the input heart valves, the tricuspid and the mitral, close.
We know that the sound is primarily associated with the
valves because if the valves are surgically removed the
contracting heart produces only a slight sound. A number
of theories, some 40 of them, have been proposed to
explain the first heart sound. Two conjectures, namely
that the sound is a reverberation of the valves slamming
shut and the other that it is the sound of turbulence of the

*Interior of the left side of the heart. The arrow indicates the
course of the blood. But what causes the first heart sound?*

surging blood, can be ruled out on various grounds. One suggestion which I subscribe to is that the major contribution of the first heart sound is due to the tensing of those muscles, the *chordae tendinae*, which pull the vanes of the valves inward to prevent their bulging as the ventricle of the heart contracts.

However, the heart sounds which have been of most interest to physicians are the murmurs associated with turbulence of blood flow produced by malfunctioning valves such as may result from rheumatic fever. Because heart murmers generally have high frequency components (Figure 2), they are readily detected by the mechanical stethoscope. Because of its low frequency, the acoustical analysis of the first heart sound requires expensive, sophisticated equipment such as that employed for the evaluation of motors.
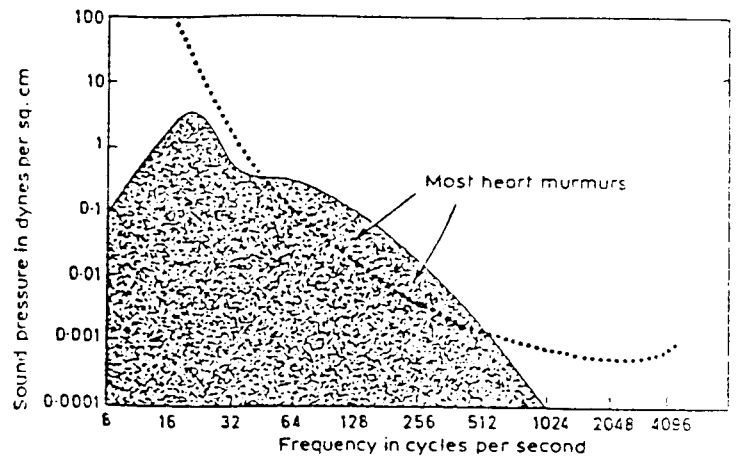
Figure 2 *The spectrum of vibrations of the heart (cross hatching). The maximum sound pressure occurs at 24 Hz, the first heart sound. Note that most of the vibrations of the heart lie below the threshold of audibility of the unaided human ear (dotted line). The muscle sound at the forearm when the hand supports 8 kg is faintly audible to the unaided ear*
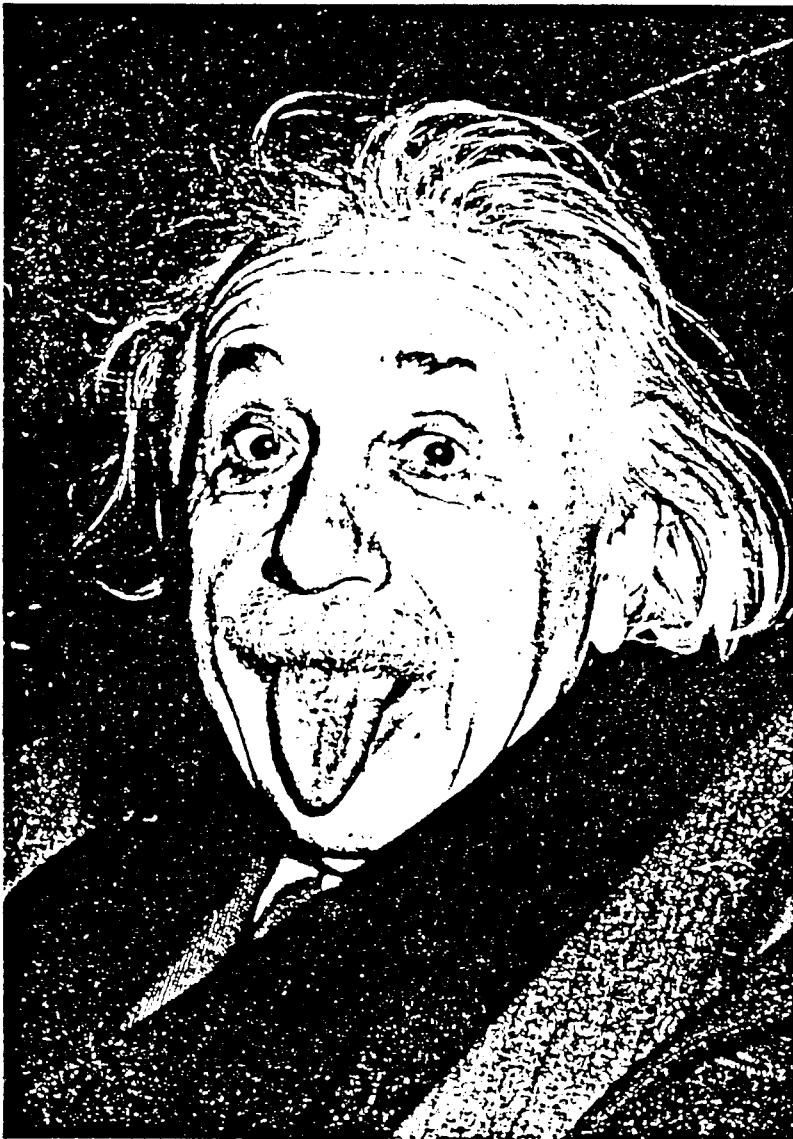
"Imagination is greater than knowledge."
A.E. died April 18, 1955, on the 179th anniversary of Paul Revere's ride and the 49th anniversary of the San Francisco earthquake. Shown here when asked to smile for a picture on his birthday.

An old man was passing out this leaflet in downtown Portland in 1980 or 1981. He was tall and thin, sitting bent over on a bench. He had a long white beard and colorful clothes. He was blind, and his long arm stuck right out into the crowd passing by. He had two little leaflets in his hand, and said to the passersby, "Take one or the other. Please take one." I was in my first year of air car research.

RETURN OF MAXWELL'S DEMON
Introduction

This book is about the Kadenacy Effect. This is the second book in my series on Maxwell's Demon. The first book, MAXWELL'S DEMON GETS A JOB, contains four chapters that I've written to fill in the gaps in the textbooks on compressed air, with a collection of supporting documentation. RETURN OF MAXWELL'S DEMON contains sections documenting Kadenacy Engine theory, pulsejet engine theory, and pulsed-jet pump theory. Further volumes such as MAXWELL'S DEMON RIDES AGAIN and MAXWELL'S DEMON AND THE LOST WORLD will document these same fluid wave phenomena that make it possible to design self-fueling air cars. There are many more-or-less well-known devices such as water ram pumps and cryptosteady pressure exchangers that use fluid waves to do the pumping work. (In engineering, a fluid is anything that flows, liquid or gas.)

In 1670, Christiaan Huyghens devised the first-ever engine, made up of a cannonball acting as a piston in a vertical cylinder. An explosion of gunpowder under the ball would raise it in the vertical cylinder, then it would fall back down the cylinder under its own weight. Huyghens' engine was able to pump water by the suddenness of the motion imparted to the cylinder's contents by the explosion. Behind the high pressure explosion pushing the ball up the cylinder, there was an implosion, a sudden and short-lived partial vacuum or rarefaction wave, in the cyinder. Because of the subatmospheric pressure, or depression, in the cylinder, the atmosphere added its own energy to this engine cycle to force the next cylinderful of water into the rarefied space under the ball. Then the ball fell back down the cylinder, pumping the water back out. Each explosion would "scavenge" the cylinder by clearing it of any water left over from the last cycle, by means of a high pressure blast or compression wave.

Huyghens' basic discovery--the depression left inside a closed cylinder after a sudden outward pulse--was the working principle that Thomas Savery used in taking the engine to the next stage in its development. The alternating wave in the fluid to be pumped comprised a fluid piston that did the pumping. Pulses of steam alternately scavenged the two chambers of Savery's engine, and each chamber would automatically refill with water because of the depression left behind each scavenging pulse. Savery's engine had no moving parts except valves. The mass exit of the chamber's contents left a depression that induced the next chamberful of water, and a pulse of steam pumped this water out. The pulsometer pump, which was manufactured from 1876 to at least 1938, used the same principle.

Newcomen's and Watt's cumbersome piston engines, laden wth expensive moving parts, took precedence in the developing engine industry over the simpler fluid piston principles that Huyghens and Savery pioneered. This was, in effect, an early version of engineered obsolescence.

Bob Neal's patented Compressor Unit is the only device I know of that can provide the essential hardware needed to run a self-fueling air car. Neal filed his patent in 1934; a trip to Washington with the working model secured him a patent in 1936; shortly thereafter he had to abandon the project due to harassment by the Nazis. The Nazis perfected the pulsejet engine in 1943; the French were developing their own pulsejet, which had no valves, at the same time. This pistonless piston engine--a tube containing a self-sustaining fluid piston--proved to be the most powerful engine for its size that was ever built. And none of the pulsejet's inherent defects, such as high noise levels or wasted residual energy in the exhaust, apply to Neal's "equalizer" since the equalizer is inside a tank full of compressed air.

Michel Kadenacy filed the first of his twelve U.S. patents in 1934, eight months after Bob Neal filed his patent. Kadenacy filed his French patents on August 1, 1933, a few months after Hitler took power. Kadenacy's system of scavenging and charging an engine cylinder is still the theory behind two-stroke engine tuning. The Kadenacy Effect could be called the Huyghens Effect, but Huyghens already had a principle named after him. The Huyghens Principle describes the tendency of each wavelet in a wave field to propagate its own wave field. The work of Huyghens became the foundation for the work of James Clerk Maxwell, the founder of mathematical prediction in theoretical physics, who predicted the discovery of overunity dynamic pressure exchangers (Maxwell's Demon) in his textbook THEORY OF HEAT in 1870.

Arkansas shoemaker Bob Neal's compressor unit is Maxwell's Demon reduced to hardware, and it's also the logical idealization of Huyghens' first-engine-in-history. The Neal Equalizer will one day be considered a refinement in engineering thought that paved the way for the age of sustainable technology to take hold in the 21st century.

Scott Robertson
~~Luther Rangely~~
Grass Valley, California
Groundhog Day, 1989

Chapter Five
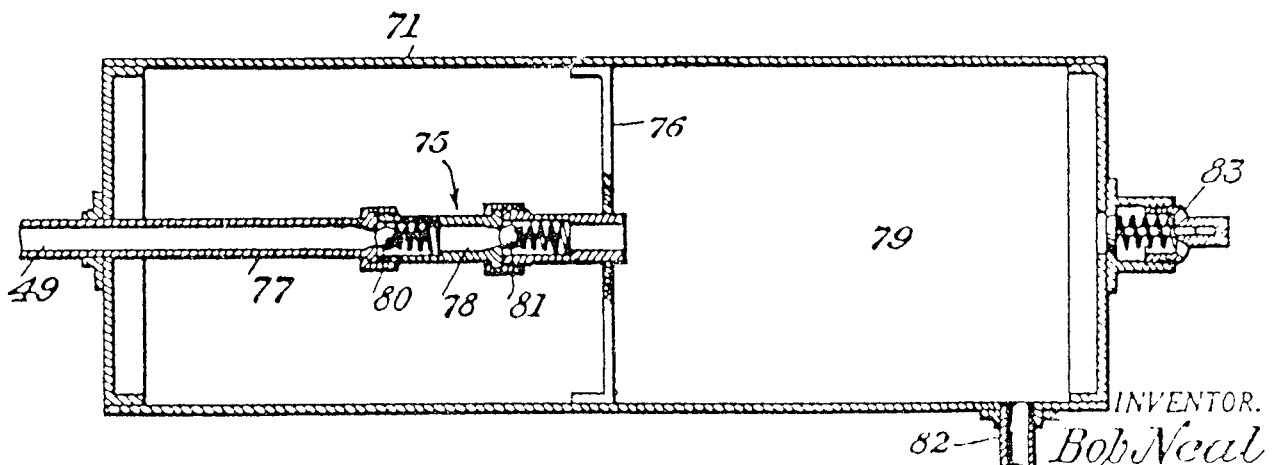
PARAPHRASES OF IMP-POSSIBILITIES

Establishment science get out of the way! Someone
'round here is fixin' to change the static potential.
Dolphin-powered air-recycling machines, an exclusive
interview by the author, excerpts from books, magazines,
newspapers, and patents.

Contents

Resonance in Closed-ended Pipes
(written for this work by a retired mechanical engineer)

Considering only pressure changes--that is, compressions, C, and rarefactions, R--in a closed pipe whose length, L, is adjusted to be one-fourth the wavelength of the entering sound (Fig. 1), let us follow successive regions of C and R as they move into the pipe and are reflected from the ends, remembering that change of pressure phase occurs at the open but not at the closed end.

Fig. 1)
resonance
in 1/4- or
3/4-wave
closed-end
tubes

$\overset{\bullet}{C}_2$ $\overset{\bullet}{R}_1$ >C$_1$

$\overset{\bullet}{C}_2$ $\overset{\bullet}{R}_1$ <C$_1$

$\overset{\bullet}{R}_2$ $\overset{\bullet}{C}_2$ >RC<

$\overset{\bullet}{R}_2$ $\overset{\bullet}{C}_2$ RR>

$\overset{\bullet}{R}_2$ $\overset{\bullet}{C}_2$ <RR

$\overset{\bullet}{C}_3$ $\overset{\bullet}{R}_2$ CCC>
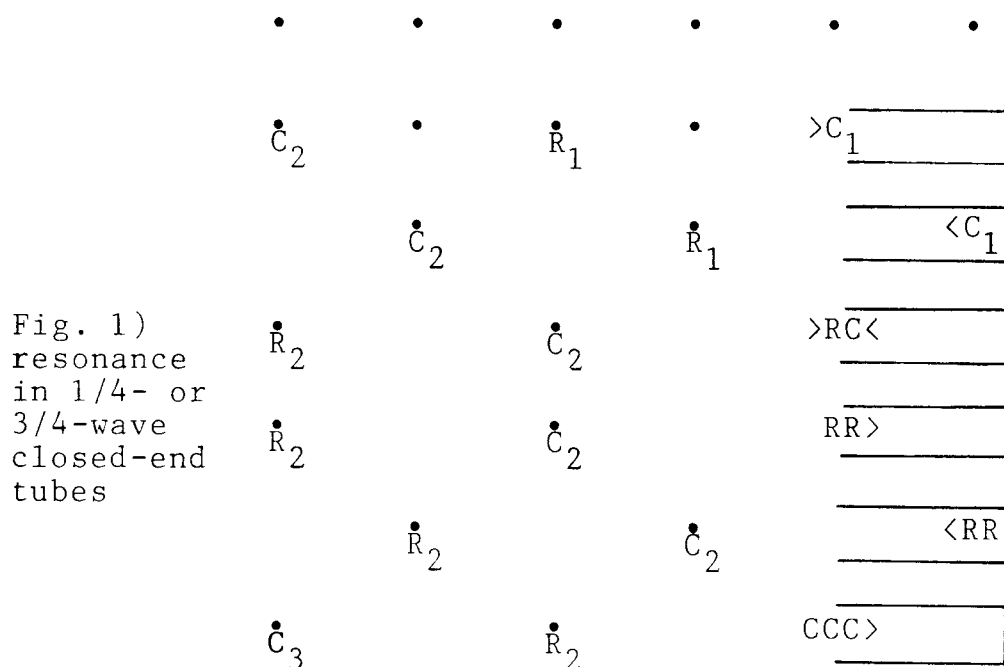
The compression wave C_1 enters the pipe, is reflected at the closed end, and reaches the open end just as R_1 is about to enter. As R_1 enters, C_1 is reflected back in the opposite phase as an R, and unites with entering R_1. The now amplified R_1 is reflected at the closed end, and on returning to the open end, is reflected as an amplified C, which is further amplified by uniting with entering C_2.

Thus the pressure disturbance traveling back and forth within the pipe is greatly augmented, and an intensity is built up within the pipe which is very much greater than that in a corresponding length of the incoming wave itself. In this way, a sound of such low intensity as to be inaudible outside the pipe becomes loud and clear on reinforcement be the resonance built up in an air column properly tuned to respond to it.

The same phenomenon occurs likewise if the closed pipe is three-quarters wavelengths of the incoming wave. Compression C_1 then unites with rarefaction R_2, and these again with C_3 and R_4; also, C_3 meets rarefaction R_3 and C_4. Similarly one gets resonance in a closed pipe if the length is any ODD number of quarter-wavelengths (see Fig. 1 again).

Resonance, closed pipe, for L = 1, 3, 5, 7,... $\frac{\lambda}{4}(2n-1)$

or for a given pipe length, response will occur for waves of length

$\lambda_{1, 3, 5, 7, 9,...}$ = 4L, $\frac{4L}{3}$, $\frac{4L}{5}$, $\frac{4L}{7}$, $\frac{4L}{9}$, ...

ENGINEERING

JAN. 5, 1940

SUDDEN DISCHARGE OF AIR FROM A PRESSURE VESSEL.

By S. J. DAVIES. D.Sc.

THE object of the experiments described here was to study the pressure conditions in a vessel following the sudden discharge of compressed air from the vessel. The apparatus used in the experiments is illustrated in Figs. 1, 2 and 3, page 18. It consists of a cylinder having an internal diameter of 4 in. and length of approximately 13 in. The cylinder is closed at one end, and is provided at the other end with an orifice $3\frac{5}{8}$ in. diameter, in which is seated a valve having a masking $\frac{3}{4}$ in. long. For convenience, a cylinder used in previous experiments was employed. It will be noticed from Fig. 3 that the closed end contains a shallow recess, and that the valve embodies a cylindrical internal extension. These modifications did not in any way affect the validity of the experimental results. The external mechanism shown on the left in the figures is provided for holding the valve on its seating while the vessel is being charged with air to the required pressure, and for releasing the valve when desired. The valve is forced from its seating by the pressure of the air in the vessel and thus uncovers the orifice, the masking ensuring that the valve will have attained a high speed before the end of the masking clears the discharge orifice. This valve mechanism, as will be seen in Fig. 3, comprises a spring-loaded lever which presses on the valve in the closed position and can be disengaged from the valve by striking an external tripping arm. The photographs reproduced in Figs. 1 and 2 show the valve in the closed and open positions, respectively.

The experiments consisted in charging the vessel with air at varying pressures, releasing the valve, and making observations of the minimum pressures reached in the vessel at the points marked A, B, C and D, in Fig. 3, and of the time intervals. These observations were made by means of the "Sunbury" cathode-ray oscillograph, made by Messrs. The Standard Telephone Company. To obtain the greatest possible accuracy, the calibrating unit of this instrument was used for measuring the minimum pressures reached in the vessel. For this purpose, provision was made to place the pressure elements and the calibrating unit, respectively, at the points A, B, C and D, and contacts were arranged so that the horizontal movement of the spot across the screen of the oscillograph commenced at the instant the end of the valve masking cleared the discharge orifice of the vessel.

As a first experiment, the vessel was charged with air to a series of initial pressures ranging from 0 lb. per square inch gauge to 60 lb. per square inch gauge, and the valve then released. In each case the value of the minimum pressure reached at the point A was measured by means of the calibrating unit of the indicator. The values thus obtained are recorded in the form of a curve of minimum pressure against initial pressure in Fig. 4, and it will be seen that, for all initial pressures above 1 lb. per square inch gauge, a depression was recorded in the vessel at A, following the discharge of the compressed air, the depression for the initial pressure of 60 lb. per square inch gauge reaching the value of +3 lb. per square inch.

In a second experiment, the vessel was charged with air to an initial pressure of 40 lb. per square inch gauge and, following the release of the valve and the discharge of the compressed air, the value of the depression reached at the points B, C and D (in addition to A) were measured. The values thus obtained are shown in Fig. 5, as ordinates on a base represented by the vessel itself, and it will be seen that the depression is greatest at the closed end of the vessel and least at the discharge orifice.

In order to obtain an indication of the time of occurrence of the maximum depression at points A, B, C and D in the second experiment, the calibrator diagram was photographed at each point with an applied static depression slightly less than the maximum depression occurring at the point concerned. It was found that at each point in the vessel the maximum depression was reached about 0·006 second after the commencement of opening of the orifice, but the accuracy of the time measurement was not sufficient to permit conclusions to be drawn concerning the exact instants of time at which the maximum depressions occur relative one to the other.

By repeating this experiment with atmospheric pressure applied to the calibrating unit, it was found that at all points the pressure in the vessel fell below atmospheric pressure about 0·0035 second after the commencement of opening of the orifice, and returned again to atmospheric pressure about 0·007 second after the commencement of valve opening.

The apparatus is designed to give a rapid opening of a large area of discharge orifice in the vessel. In order to obtain a measurement of the time taken to open the orifice fully in the second experiment, two time points were determined, one when the valve masking commences to clear the orifice and the other at the full opening of the orifice, i.e., when the end of the valve masking had moved $\frac{3}{8}$ in. away from the orifice. This time interval was found to be 0·0019 second, showing that the orifice is already fully open before a depression is reached at any point in the vessel. By way of interest, it is indicated that the time for full opening at 20 lb. initial pressure was 0·0026 second, and at 60 lb. initial pressure 0·0015 second.

Conclusions.—The experiments show that the sudden discharge of compressed air from the vessel leaves a depression in the vessel even with the lowest initial pressures, and that this depression increases as the initial pressure increases, (experiment 1.) The distribution of pressure in the vessel shows that the depression is greatest at points most remote from the orifice, (experiment 2.) The time intervals in which the depression occurs are short; the first fall below atmospheric pressure begins some 0·0035 second after the commencement of opening the orifice and the existence of the depression is not of long duration; certainly no longer than 0·0035 second.

DISCHARGE OF AIR FROM A PRESSURE VESSEL.

FIG. 1. (CYLINDER WITH VALVE CLOSED.)

FIG. 2. (CYLINDER WITH VALVE OPEN.)

Fig. 3.

Fig. 5.

Fig. 4.

Are the noises made by some vibrating part located inside of the blowhole, but below its external valve? Such a vibrating mechanism apparently exists. The nasal passage underneath the blowhole contains a number of diverticula or air pockets. Just below the surface orifice, these expand laterally on either side of the central canal. Farther down there is an anterior pocket as the single opening divides into the nares at the level of the skull. There are also tongue-like projections within the air passage which probably act as secondary valves during submersion. "The overlapping and close-fitting-together of the lips and walls of the passage form a series of check valves . . ." (Lawrence and Schevill, 1956, p. 147). One or more of these could conceivably vibrate or clack either by muscular action or by a rapid flow of

Porpoises and Sonar
Winthrop N. Kellogg
1961, University of
Chicago Press, 71-72
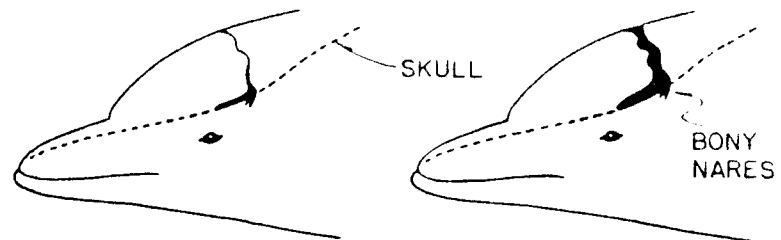
Fig. 5.—Diagram showing probable action of the blowhole in closed (left) and open (right) positions. The external valve and the anterior-posterior projecting processes are indicated. Auditory vibrations could conceivably be made either by the lip of the blowhole, or lower down in the passage (modified from Howell).

air. Even if the external blowhole were closed, the inner structures might well be free to operate. The general arrangement of some of these parts (excluding the lateral air cavities) is diagramed in Figure 5. This, we are inclined to believe, is the most likely source of the dolphin's noises.[2]

"Stunning Sounds"
an episode of The Nature of Things with David Suzuki, broadcast 8-9-88 on PBS; editor's note:
Dolphins and whales might use sound waves or shock waves to stun, disorient or even kill small fish so they can catch them easier. A scientist put his hand on a whale's nose to find where the sound was coming out, and when he found the spot, the shock waves pushed his hand away from the whale's nose, and he couldn't hold his hand down. Sound waves travel five times faster in water than in air, and go out in all directions. A firecracker set off near a glass jar in the water will cause the jar to explode due to shock waves transmitted by water. Consider the implication of species having to adapt to its own built-in Saturday Night Special. These animals of superior intelligence must recycle the same air over and over to make the sounds, doing this with a pulsating one-way valve in their head called the monkey's muzzle. This suggests that fluid standing waves are nature's way of re-using air pressure over and over.

Mind in the Waters, ed. Joan McIntyre, Sierra Club Books, 1974, San Francisco, page 137

BREATHING:
OPEN BLOWHOLE

AIR

LIP

AIR
SAC

FROM LUNGS

SOUND PRODUCTION:
CLOSED BLOWHOLE

SOUND

AIR TO LUNGS
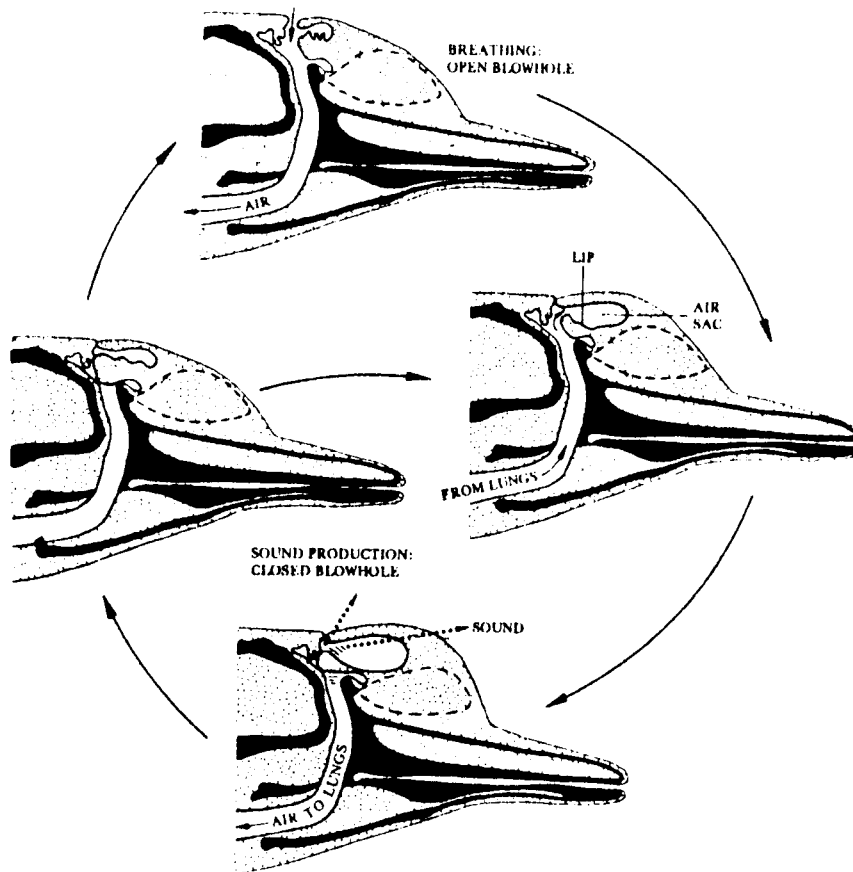
LUNGS

This diagram shows the relation of breathing to vocalizing in the dolphin. In breathing (top drawing), the blowhole is open and air is sucked into the lungs. In vocalizing (middle right drawings), the blowhole is first closed and air from the lungs is forced into an air sac near the top of the dolphin's head. As the air sac swells with air, the forehead swells. Then the dolphin closes the lip of the air sac (bottom drawing) and releases air back toward the lungs. This makes the air sac lip give a "Bronx cheer" like releasing air from a baloon. These are focused by the melon and are bounced off the bones of the jaw and brain case. The drawing at the middle left shows the deflated air sac. The dolphin may either refill her lungs by opening the blowhole or make more sounds by refilling the air sac.

Some sounds are so loud that if we could hear them it would feel like your ears were laying next to a jackhammer breaking up a sidewalk. People who have lived around dolphins say that you can feel the sound by placing your hand in front of the dolphin's head. In order to protect the dolphin from the intensity of his own sounds, the skull around the sound production area is thickened to prevent the dolphin's nerves and brain from being shattered by continuous sonic bombardment.

Interview with Bob Neal's Son
Luther Rangely, October 14, 1988

(Floyd Neal started right in describing the engine hardware
in some detail. I got my tape recorder hooked up while he
was talking, and steered the conversation toward the equalizer,
or "special valve" in the tank.)

LR: Did you see the inside of the tank where that one special
valve was?
FN: Now he had a special valve where he could load the tank
with very little pressure. That was a--the valve looked like
an extremely skinny, long plumb bob. That's about all I can
remember, like I say, I was just a small boy.
LR: How old do you think you were? Maybe 16 or so?
FN: Oh no, I was younger than that. Oh, probably maybe seven
or eight years old, and probably the last I had anything to do
with it, 'cause I was out going to school, probably maybe 13
to 15. But I couldn't really give you any good detail.
LR: Do you know about how long or how big the tank was?
FN: Well the storage tank was a streetcar tank. If I remember
right they were probably about 16 inches by probably 4 feet.
LR: Pretty big tank, huh?
FN: Yes, the reason he used that, it was available. You
probably wouldn't have to have that big a tank. As far as
that goes, it was actually just to start it with. 'Cause then
you see it starts producing air on its own.
LR: Do you know what the principle is of being able to get
the low pressure air into the tank?
FN: That was, he felt, the valve. It was a type of valve that--
it was a double valve of some sort.
LR: Double check valve according to the patent.
FN: Yeah, and you could load the tank with a lot less pressure
than was in the tank.
LR: Did he ever talk about water hammer or pulsejets?
FN: No...
LR: You know when your water pipes start buzzing, vibrating
in the wall, that kind of principle is what makes pulsejets
work, and I was thinking possibly it was similar to that.
FN: I couldn't really tell you. Have you come up with anything
that you're working on?
LR: Well no, I'm just a researcher, and this is so far the
only patent I've found that actually said what it was trying
to do. It doesn't say what the working principle is but I
think I've figured it out. I think if you make the air vibrate,
then it organizes itself into high pressure zones and vacuum
zones, and the vacuum waves can be used to let that low pressure
air in. So it's kinda like a ram pump, and pulsejets and other
wave-type machines that work on causing the fluid to vibrate
and make waves. So that's what I think it is, it seems to
make sense to me, and that's what my research seems to lead to.
FN: Well it's important to get that research. Have you actu-
ally developed any kind of engine?

LR: No, what I've got is, I've built the tank and I put the two check valves inside the tank, sorta like the way it looked in the patent, and I've got an air motor running a rotary compressor, to put the low pressure air in. And I'm getting low pressure air into the tank all right--

FN: About what kind of pressure?

LR: About maybe ten pounds--I can get it in at two pounds but if you run the air motor faster it pumps it up to a higher pressure. It's still going in at a much lower pressure than what's in the tank. So I think it's working, and I think having the compression and engine cylinders on the same crank-shaft is the secret. That's why I'm running the compressor direct with the air motor, so they're going at the same speed.

FN: Sure.

LR: Yeah. I think that's your dad's trick is to have the pulsations entering and leaving the tank at the same time so you just have that very clear, distinct wave in it.

FN: Does Mr. M. have a picture of the engine?

LR: Well he says he's got an article but he says it's off in a box somewhere and he doesn't even know where to start looking for it.

FN: I thought he might have a photograph. Of course you're trying to discover something that's altogether different?

LR: Well, yeah, I'm mainly sort of an air car advocate you might say. I'm exploring the whole area and I'm looking at all the different systems I can find, and so far I think this is the best, and I'm concentrating on it. And hopefully I'd like to build an air car that uses this principle--is the patent owned by someone now?

FN: No, you know, it's run out. It's public domain. I was thinking about, oh a few years back, renewing it, but then it wasn't right for me and I just didn't deal with it and now I have no interest in it.

LR: Well it seems to me like it sort of works similar to a perpetual motion machine, which is supposed to be impossible.

FN: You know, when he patented that thing--he had trouble patenting it. Because they notified him and told him that the United States Patent Office was not interested in perpetual motion. And he fired a letter back to them and told them he wasn't either, he just wanted to patent an engine that was functional. And as a matter of fact he got busy and made a little--a small prototype--a hand carried model. And as a matter of fact I went with him to Washington when I was a little boy, and he put it up on Garrett Whiteside's desk-- he was top man at the time--started the thing up, and he called in the investigative men, and they had to issue him a patent. You can't argue with a functioning engine, right?

LR: That's right. Well that's great. So the little model had the tank and the valve and the--

FN: Yes, it had everything and he could actually carry it in.

LR: Well that's pretty good because they say in no uncertain terms that they won't grant one, and there's so many air car

patents that--
FN: Yes. Don't ever mention perpetual motion.
LR: Right. Have you ever heard of anybody else that's done
something like this with air?
FN: No, I heard there was someone in the South, a couple
years ago, but I don't know if it was just rumors or what.
But I didn't really know about it.
LR: What was your dad's relationship with Mr. M.? They were
corresponding with each other? Or they were friends?
FN: Well, I don't really know how they got--oh, I know what
it--my dad's sister, my aunt, and her husband were living in
California somewhere, and I think they were sitting in a city
park or something, and the conversation just came up, during
the conversation, and my uncle said, well, his brother-in-law
was--oh, it was "odd things"--but he said his brother-in-law
was working on an engine that ran on air. And Mr. M. heard
that, and got interested, and got his address and everything
and came down. I remember when he came down. That's how
that started. I think that was about '45.
LR: Well I've been working on this research for nine years
and someone introduced me to Mr. M. over the phone. We had
a three-way phone conversation and he started talking about
this and we tracked down the patent. And I thought about it
for about a year and a half before I figured out this wave
principle for how it might work, and got some research to
back it up. I think we're doing pretty good. Would you like
to be on my mailing list in case we get something going and
put out a newsletter?
FN: Yeah. You know, there was another fellow that was interested
in this; that was William Lear. He was kind of interested
in seeing an air engine a couple of years ago. He came down
to see me a number of times also. And that was over this
valve--in the tank.
LR: Did he look at it?
FN: Well, I didn't have it. He came down to my place.
LR: Oh. He's sort of like me, he was trying to get infor-
mation from you.
FN: Right. And I don't know, he did come up with some sort
of an engine--steam, though, I think--and busses in L.A.,
years ago, and also in police cars. But I don't know.
LR: Was he adapting your father's invention?
FN: Well, at the time, he didn't know if he was gonna go air
or steam.
LR: Mr. M. says you had to stop making this or stop developing
it because somebody came from some government or something.
FN: That was during the war years?
LR: Uh-huh.
FN: Yes, as a matter of fact, my sister was even kidnapped
over it. Germany wanted it real bad. They tried to buy it.
And of course my dad didn't do business with foreign powers
or the enemy. Then they tried it their way. And they
threatened him and said they'd have his family members killed
off one at a time. What happened is he dismantled it, and
scattered the parts all over the countryside. They just

literally scared the old boy to death.
LR: That was the Germans, huh?
FN: Uh-huh.
LR: That's pretty bad.
FN: Yeah. Poor timing for him.
LR: That was right after he got it patented?
FN: Yes. His first engine was a lot bigger. The first one
was fourteen cylinders--air compressors--it was a big "V".
Then he decided that was too much, and then his last one was--
he called it the "Model 39"--it was just half a block. It
looked very similar, and the same size, as an old straight-8
Buick, because the hangers and everything would drop right in
on a straight-8 Buick. Because that's what he had at the time,
and he wanted that to drop in there, and use the same drive
line and everything. The engine actually looked like a letter T.
LR: A letter T?
FN: A letter T. Just straight like an old straight-8 and it
was a "V" out front where the two pullers were, set a little
off to the side. The crank on that was perfectly round. The
pullers had a little larger throw. The engine was basically
the same thing cut in two from the original patent. Seven
compressors is like fourteen, working both up and down. I
remember it, he hooked it up to a machine lathe and had it
running that. It worked!
LR: All right. Well I think it'll work because I'm partially
showing it myself, a pretty crude, rigged-up system.
FN: Well, have you actually produced an engine?
LR: Well, not an engine, I'm just putting components together,
I've used an air motor and I'm running a compressor with it,
and I'm having that compressor put the air back into the tank.
It's not putting enough back in the tank yet. Does his air
motor cylinder--did they use the air pretty efficiently or
did they let the air come in through the whole stroke and then
exhaust it?
FN: Well, evidently it was efficient but he had no way of using
the same air. His engine, I believe it would fill the tank
I believe to 140 or 150 pounds and then the excess would escape.
LR: And then the exhaust from the engine just exhausted, right?
It wasn't recaptured?
FN: Yeah, just like a regular combustion engine.
LR: Was the safety valve letting air out all the time or only
when it was idling?
FN: Well, it maintained that pressure. And if I remember
right, I could hear the air leaving all the time, so I think
it was producing quite a bit more even under load.
LR: So even when it was running, the safety valve was letting
out a kind of a regular spurt?
FN: Yeah. Uh-huh. It made a hissing noise because he didn't
muffle it. He just turned it loose.
LR: That could be a key. If the safety valve was letting air
discharge all the time, then that's important because it could
be causing the pulsejet effect. Sudden discharge like that--

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when you suddenly let a burst of air out through your safety
valve--can create a vacuum inside the tank.
FN: Sure. That's what it is, it's one of the features. That's
what he said, "The valve is the feature." And like I said,
as a small boy, I was thinking of other things.
LR: Right. Well, those are pretty much the questions I had
for you, I really thank you for taking time with me--
FN: Well, I wish I could help you more, I just can't remember
the finer details.
LR: Well, that's fine, I think that the patent's pretty complete,
but they just left the working principle out. It's probably
just patent lawyers' tactics, you know.
FN: Yeah, sure. That's the legal people for you.
LR: Yeah. All right, Mr. Neal, I appreciate your taking time
with me.
FN: Well I appreciate talking to you. Hope it works out.
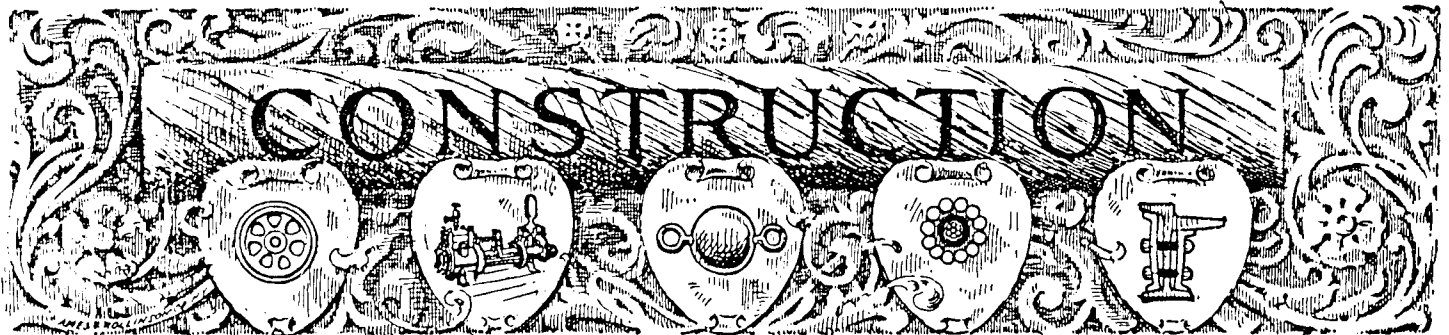
Fig.6.
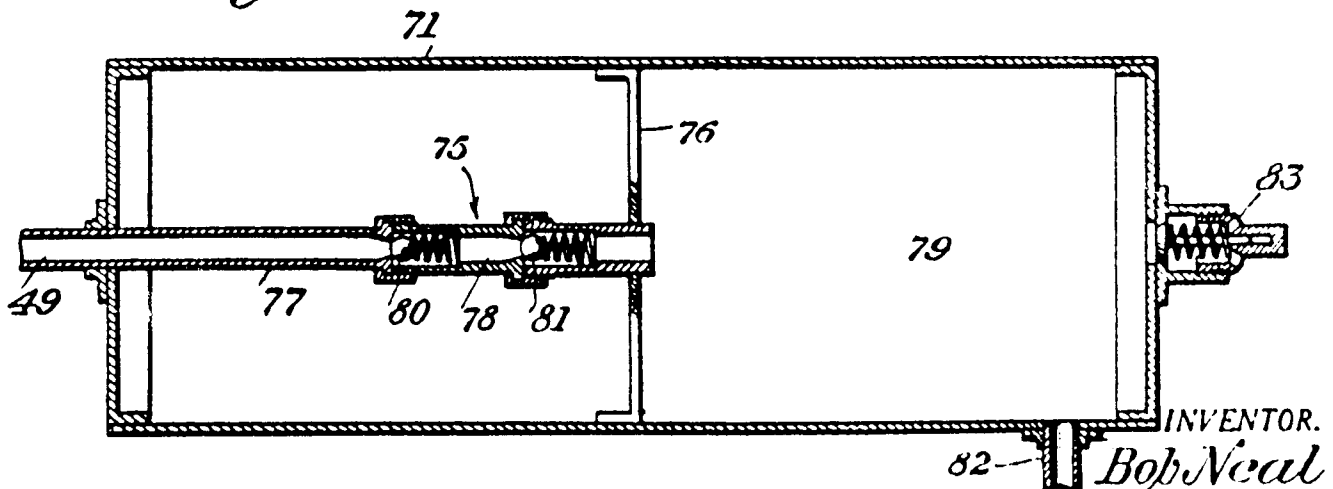
Bob Neal's U.S. Patent #2,030,759 shows an equalizer (75) that
lets the compression cylinders pump low pressure air into a
high pressure tank (71) without compressing it to get it in.
Possibly the Maxwell's Demon that physicists have been debating
for over a hundred years, the Neal Equalizer may decrease the
cost of compressing air to nearly zero.

Feb. 11, 1936.   B. NEAL   **2,030,759**

COMPRESSOR UNIT

Filed Jan. 9, 1934   3 Sheets—Sheet 1

Fig.1.

Fig.5.

INVENTOR.

Bob Neal

BY

ATTORNEY.

Fig.2.

Fig.4.

INVENTOR.

Bob Neal

BY

ATTORNEY.

Feb. 11, 1936.   B. NEAL   **2,030,759**

COMPRESSOR UNIT

Filed Jan. 9, 1934   3 Sheets-Sheet 3

Fig.3.

Fig.6.

INVENTOR.
Bob Neal
BY
ATTORNEY.

Patented Feb. 11, 1936
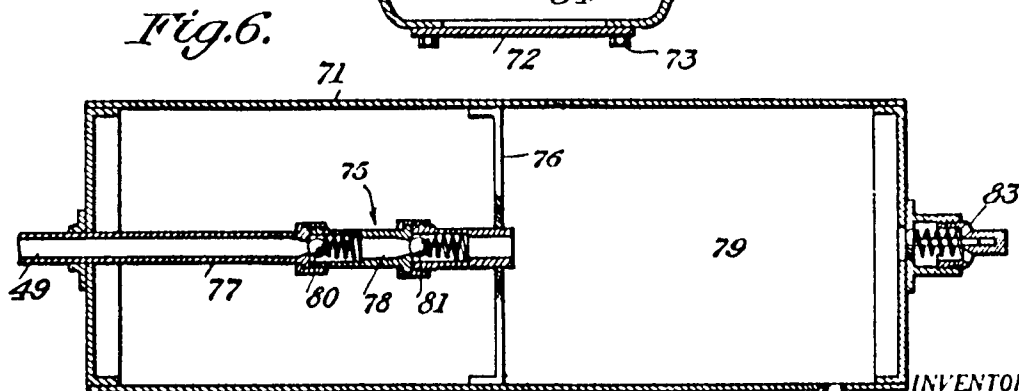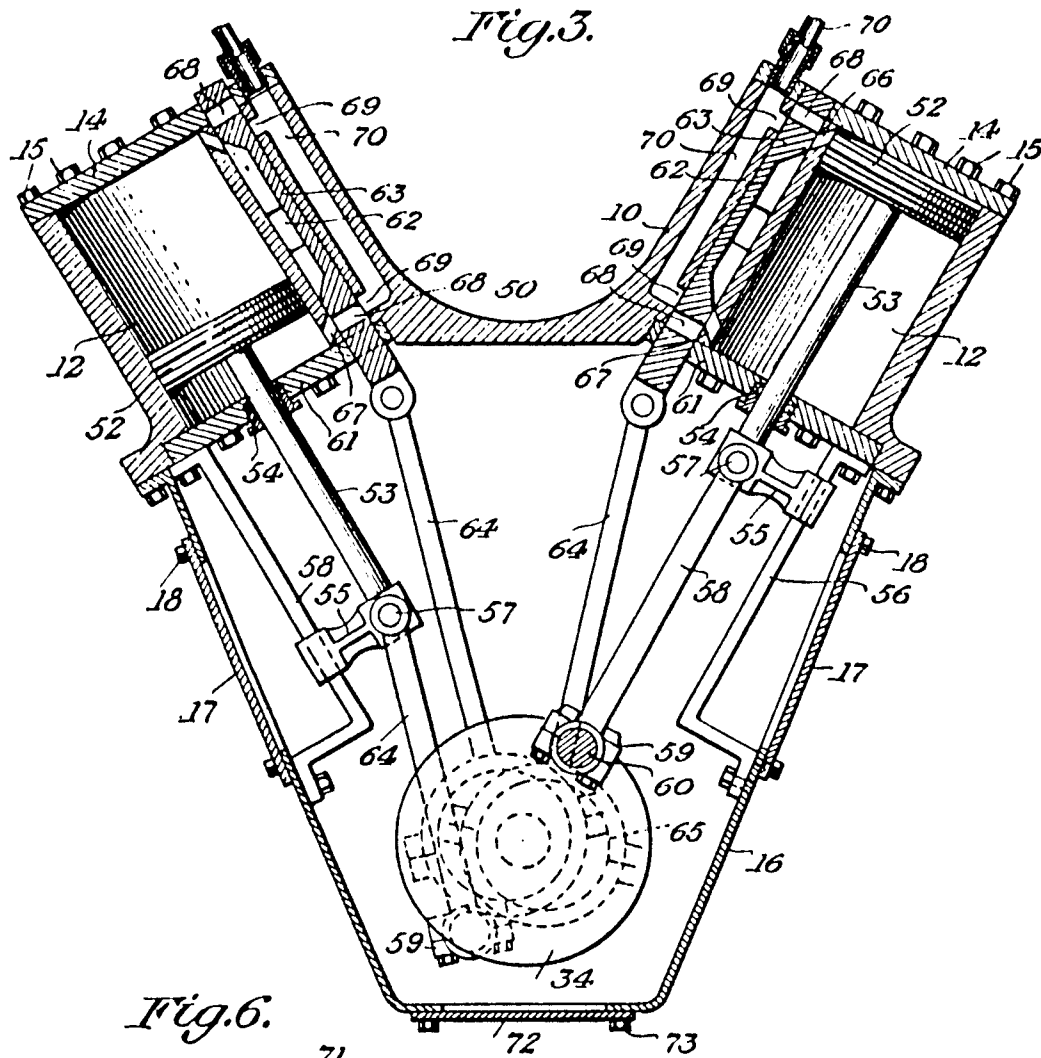
2,030,759

UNITED STATES PATENT OFFICE

2,030,759

COMPRESSOR UNIT

Bob Neal, Arkadelphia, Ark.

Application January 9, 1934, Serial No. 705,964

1 Claim. (Cl. 230—187)

The invention relates to a compressor construction, and more particularly to a combination fluid operated engine and compressor.

The primary object of the invention is the pro-
5 vision of a compressor of this character, wherein there is arranged an automatically counterbalanced crank shaft and fluid equalizers within a storage tank, which makes it possible for the said engine to operate on constant reserve tank
10 pressure so as to actuate additional equipment, the pistons for the engine being also automatically balanced and suspended when the said engine is in operation.

Another object of the invention is the provi-
15 sion of an engine of this character, wherein the same is operated from air under pressure, the said air being supplied by compressors, these being in bank with the engine construction.

A further object of the invention is the provi-
20 sion of an engine of this character, wherein the same is of novel construction, as the engine proper and the compressors are operated from the same crank shaft which is of the automatically balanced type, so that high efficiency is attained.
25 A still further object of the invention is the provision of an engine of this character, which is comparatively simple in construction, thoroughly reliable and efficient in its operation, strong, durable, and inexpensive to manufacture.
30 With these and other objects in view the invention consists in the features of construction, combination and arrangement of parts as will be hereinafter more fully described, illustrated in the accompanying drawings, which disclose
35 the preferred embodiment of the invention, and pointed out in the claim hereunto appended.

In the accompanying drawings:

Figure 1 is a perspective view of the engine constructed in accordance with the invention.
40 Figure 2 is a vertical transverse sectional view through the compressor part of the engine.

Figure 3 is a vertical sectional view through the power part of the engine.

Figure 4 is a detail elevation of the crank shaft
45 of the engine.

Figure 5 is an enlarged sectional view through one of the electric heaters for the engine.

Figure 6 is a vertical longitudinal sectional view through the air storage tank including the
50 equalizer.

Similar reference characters indicate corresponding parts throughout the several views in the drawings.

Referring to the drawings in detail the engine
55 in its entirety comprises a cylinder block 10 hav-

ing formed therein the series of compressor cylinders 11 and the power cylinders 12, respectively, the block 10 being of the V-type and closing the upper ends of said cylinders are the removable heads 13 and 14, respectively, which are se- 5
cured in place by head bolts 15, as is conventional. Beneath the block 10 is the crank case 16, which at opposite sides carries the detachable plates 17, these being held in place by fasteners 18 and such plates are seated so as to be 10
leak proof. The block 10 is chambered to provide a water jacket 19 about the cylinders, while at the forward end of the said block are water pumps 20 circulating water through the inlet pipe 21 which leads into the jacket and letting said 15
water out therefrom through the outlet pipe 22 leading from said water jacket. Next to the pumps 20 is a fan 23 operated from a belt 24 which also drives the pumps.

Working within the cylinders 11 are the recip- 20
rocating pistons 25, their rods 26 being slidable through packing glands 27 and fixed to crossheads 28, which are slidably mounted upon guides 29 secured within the crank case 16 to opposite side walls thereof. These crossheads 28 are 25
fitted with wrist pins 30 pivotally connecting therewith the connecting rods 31 which by the bearings 32 are engaged with their cranks 33 of a counter balanced crank shaft 34, which is mounted in supports 35 arranged in the crank case 16, 30
the shaft being supplied with the required bearings 36.

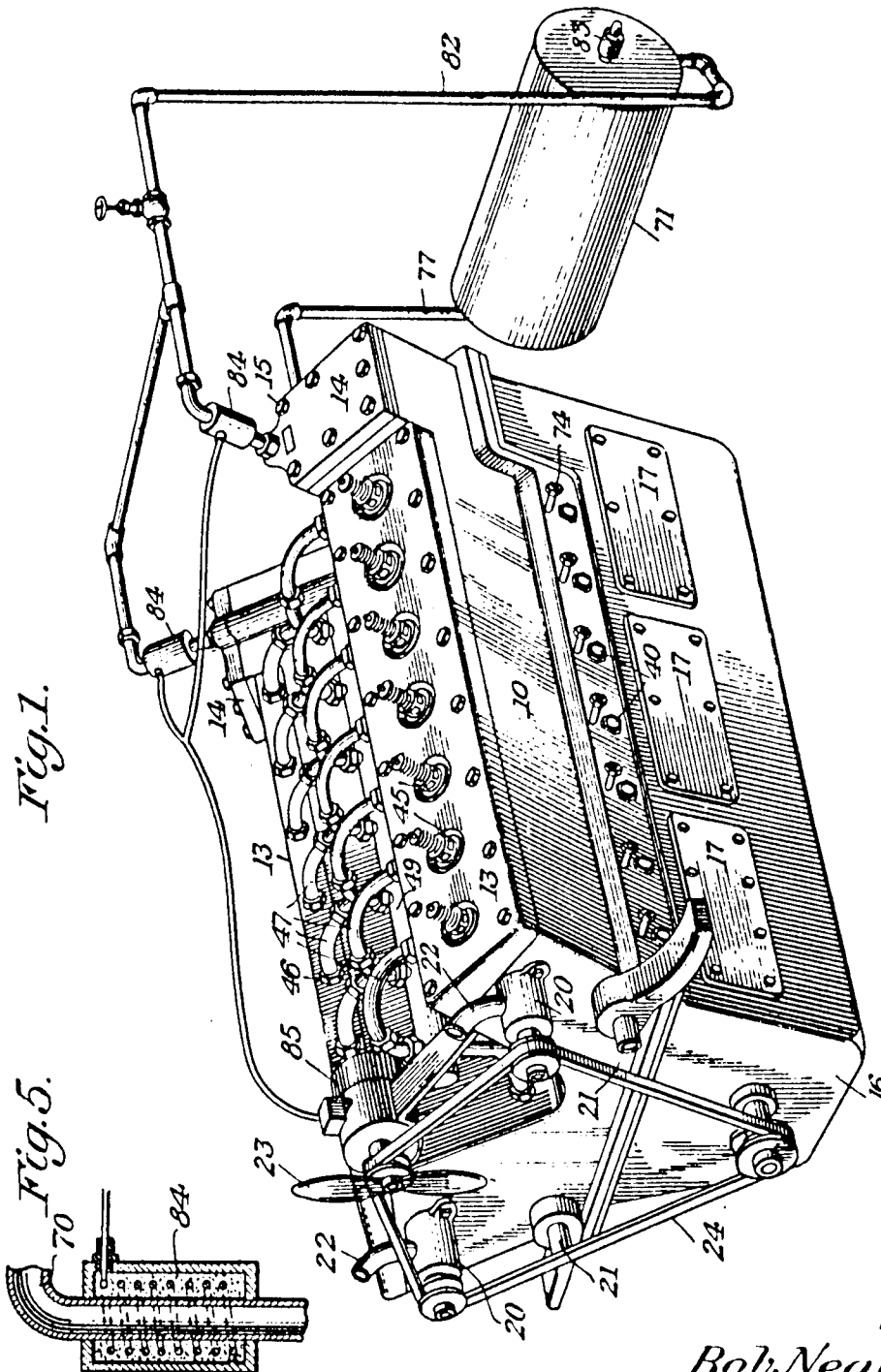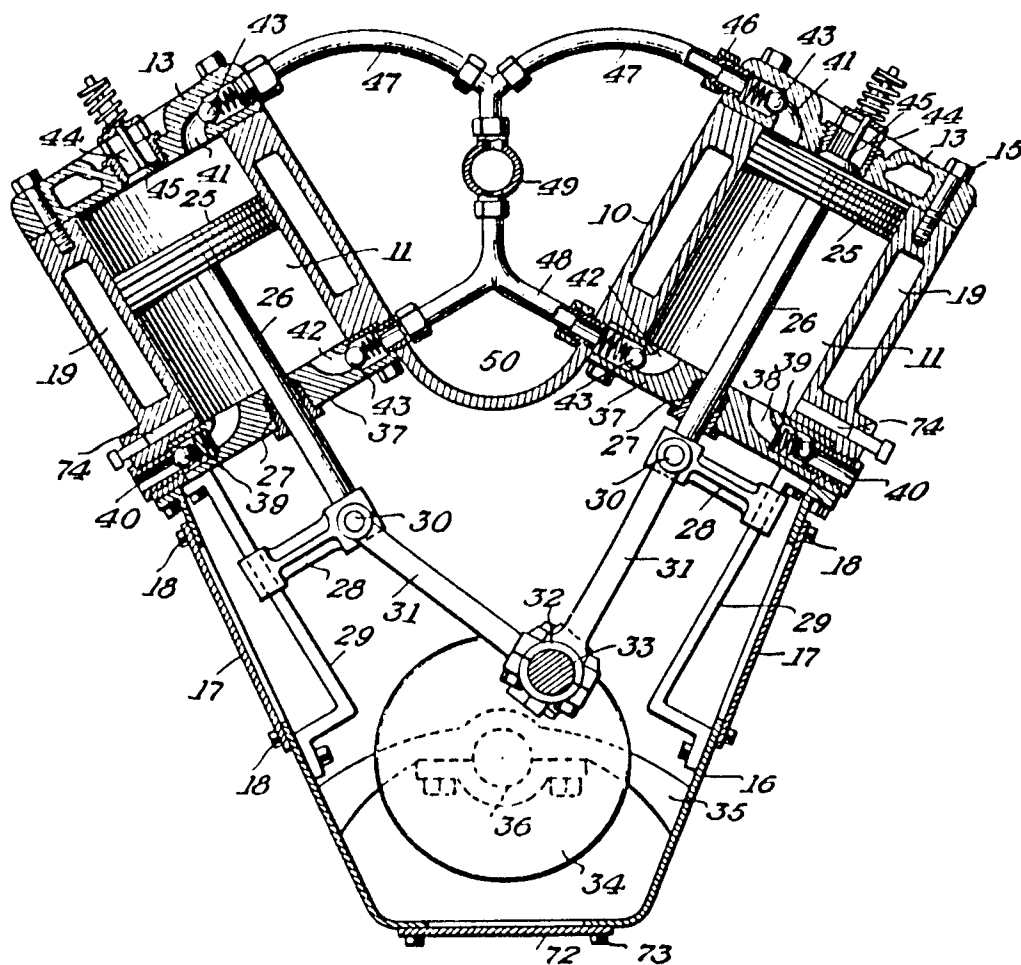The inner ends of the cylinders 11 are fitted with inner end heads 37, which are provided with air intake ports 38, these being fitted with spring 35
ball inlet checks 39, the air having admission through passages 40 opening exteriorly of the block 10. The glands 27 are associated with the heads 37.

The heads 13 and 37 are provided with the 40
compressed air outlets 41 and 42, respectively, these being fitted with spring ball checks 43, the heads 13 being also provided with the central air inlets 44, which are fitted with spring checks 45. By couplings 46 are attached to the air outlets 41 45
and 42 the outlet feed pipes 47 and 48, respectively, these leading to a main conduit 49 located in the center channel 50 in said block 10.

At the rear end of the block 10 and on the shaft 34 is the fly wheel 51, this being of conven- 50
tional type.

Working within the cylinders 12 are pistons 52, their rods 53 sliding through packing glands 54 and fixed in crossheads 55 slidably mounted upon guides 56 which are secured within the crank 55

2   2,030,759

case 15 at opposite side walls thereof. The cross-
heads 55 carry wrist pins 57 connecting there-
with connecting rods 58, these being engaged by
bearings 59 with their respective cranks 60 of the
crank shaft 34, the inner ends of the cylinders 12
being also closed by inner heads 61 with which
are associated the glands 54.

On the cylinders 12 are slide valve chests 62 in
which are the slide valves 63, these being oper-
ated by throw rods 64 actuated by cams 65 and
such valves controlling the air admission and
exhaust of air to and from the cylinders 12
through the ports 66 and 67, and these valves 63
are provided with the ports 68 for the delivery of
air under pressure from the inlet passages 69
common to a lead 70 from a compressed air stor-
age tank 71.

The bottom of the crank case 16 is fitted with a
removable plate 72 which is secured in place by
fasteners 73, and when this plate is removed
access can be had to the crank shaft 34 and the
bearings for the engine, as well as other parts
within said crank case, as should be obvious.

Leading into the cylinders 11 are the passages
74 of a lubricating system (not shown).

The storage tank 71 for the compressed air
includes therein a double check discharge nozzle
75, this being supported by a member 76 and
leading to this equalizer is an air inlet pipe 77
which has the communication 78 with the cham-
ber 79 formed by said tank. In the equalizer 75
are the spaced spring ball checks 80 and 81,
respectively, one being for the inlet side and the
other for the exhaust or outlet side of said equal-
izer. This pipe 77 is connected with the main
conduit 49, while a pipe 82 is connected with the
leads 70, the tank being also fitted with an auto-
matic relief valve 83 of any approved type.

About the pipes 70 for the passages 69 are the
electric heating units 84 which are for the pur-
pose of heating the air under pressure above a

freezing temperature when delivered from the
tank 71 to the cylinders 12.

Supported on the block 10 is an electric gen-
erator 85 which is driven from the shaft 34
through a belt 24 and this generator is included
in an electric circuit which also has the heaters
84 so that these will operate from current fur-
nished by said generator.

The storage tank 71 with the equalizer is so
constructed that it is possible to pump air into
the said tank with a tank pressure of two hun-
dred pounds, while the compressors are only
pumping against fifteen pounds or atmospheric
pressure. Outside air pressure source can be
coupled with the tank to augment that pressure
derived from the cylinders 11 of the engine.

What is claimed is:

In a structure of the kind described, a V-shaped
cylinder block provided with upwardly divergent
cylinders, end heads fitted to said cylinders at
opposite ends thereof, each head having valved
inlets and outlets, a main outlet lead between
the cylinders of the block for a storage tank and
having lateral branches to the outlets at the
inner sides of said heads, one inlet being located
at the center of each head at the outer ends
of said cylinders while the remaining inlets are
at the outer sides of the heads at the inner ends
of said cylinders, a substantially V-shaped crank
case fitted to the block beneath the cylinders, a
counterbalanced crank shaft journaled in the
crank case, pistons operating in the cylinders
and having rods extended into the crank case,
crosshead guides fitted to the sides of said case
interiorly thereof, crossheads connecting the rods
with the guides and slidable on the same and con-
necting rods operated by the crank shaft and
pivoted to the crossheads for reciprocation of
the pistons.

                                   BOB NEAL.

0762

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Commissioner of Patents
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10-18-88

   I would like to oder a complete copy of the file history,
file, wrapper and entire contents of the following patent:

Patent #2,030,759, granted February 11, 1936
Application January 9, 1934
Serial No. 705,964
"Compressor Unit" inventor Bob Neal

   Please tell me how many pages this file is, and how much
money to send you for a copy, certified.

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Luther Rangely

10-217-0762

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Luther Rangely
P.O. Box 1574
Grass Valley, CA   95945

DATE OF ORDER	10-18-88
SERIAL/PATENT NUMBER	2,030,759
FILING/ISSUE DATE	02-11-36

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PTOL-145 (REV. 7-85)

Fig. 1.

Fig. 2.

Fig. 4.

According to the invention there is provided a pressure exchanger which is arranged substantially to equalize the pressure of fluids at a plurality of pressure levels comprising a cell wheel, and end plate adjacent thereto. means for effecting relative rotation between the cell wheel and the end plate. a plurality of ducts through each of which one of said different pressure fluids is conveyed to the end plate for delivery to the cell wheel, the arrangement being such that every cell in turn is placed in communication at one end with said ducts in succession. and a common duct whose internal pressure is maintained at a level intermediate between the extreme pressures of said delivered fluids into which fluid is discharged from the other end of the cells.

The latter is a special form of pressure exchanger, that is one which receives fluids at different pressure levels and in effect discharges fluid at an intermediate pressure level, this apparatus may be termed a pressure equalizer. ◄──────

Inventor
George Jendrassik

By Kerns, Davis, Mullen ....
his Attorneys

Development and Transmission of Power from Central Stations, Unwin, 1894

Action in the Compressor.—Consider for simplicity a single-acting compressor which receives and discharges a pound of air in each revolution, and let the effects of clearance and the resistances of the passages be neglected.

Let p_1, v_1, T_1 be the absolute pressure in lbs. per sq. ft., the volume of a pound in c. ft., and the absolute temperature of the air after compression;

p_a, v_a, T_a the same quantities for air before compression;

p_1 and p_a will be used for the corresponding pressures in lbs. per sq. inch;

$r = v_a/v_1$ is the ratio of compression, a quantity determined by the mechanical construction of the compressor;

$\rho = p_1/p_a = p_1/p_a$ may be termed the compression-pressure ratio. It depends on r, and also on the thermo-dynamic conditions of the compression.

Fig. 47 shows the indicator diagram of such a compressor. During the suction stroke a volume v_a at pressure p_a is drawn into the compressor cylinder. During compression to the volume v_1, the pressure rises according to some law expressed by the curve D C. Finally, the air is expelled into the mains at the pressure p_1. In general, the compression curve will lie between two curves D F, D G, corresponding to two limiting cases. If heat is abstracted from the air during compression, so that the temperature remains constant, the compression curve will be the isothermal D F defined by the relation

$$P V = \text{constant}$$
$$= p_a v' = 27,710.$$

If no heat is added or abstracted during compression the temperature of the air will rise, and the compression curve will be the adiabatic D G defined by the relation

$$P V \gamma = \text{constant},$$

where $\gamma = 1.41$.

In ordinary compressors the curve lies between D F and D G, and approximates sufficiently to a curve defined by the relation

$$P V^n = \text{constant},$$

n having a value between 1 and 1.41.
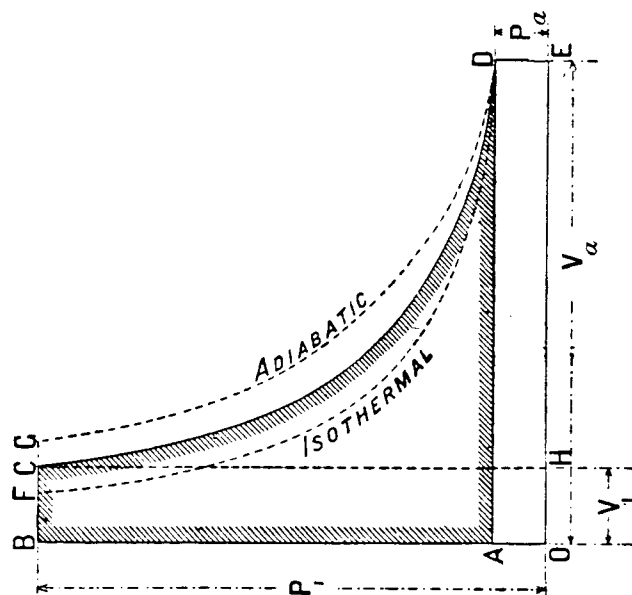
FIG. 47.

The whole work of a complete double stroke consists of three parts:—(1) The work O A D E of the atmosphere on the piston during the suction stroke; (2) the absolute work of compression E D C H; (3) the work of expulsion of the air into the mains H C B O. The effective work is the sum of these

$$- \text{O A D E} + \text{E D C H} + \text{H C B O},$$

that is, the shaded area A B C D.

Case of Isothermal Compression.—It will be shown presently that the most economical compressor mechanically would be one in which heat is abstracted during compression, so that the compression is isothermal. In that case the effective work is (fig. 48), since P V = constant,

$$- p_a v_a + p_a v_a \log_e \frac{p_1}{p_a} + p_1 v_1$$

$$= p_a v_a \log_e \frac{p_1}{p_a},$$

or exactly equal to the absolute work of compression H F D E. But the heat abstracted during compression is equal to the same

$$\frac{P_1 V_1 - P_a V_a}{\gamma - 1} + P_1 V_1 - P_a V_a$$

$$= \frac{\gamma}{\gamma - 1} P_a V_a \left[\left(\frac{P_1}{P_a}\right)^{\frac{\gamma-1}{\gamma}} - 1 \right]$$

$$= 95630 \left[\rho^{0.29} - 1\right] \text{ foot lbs.}$$

Case of Partially Cooled Compression.—The general equation for the work expended in compression is the same as for adiabatic compression, if n is substituted for γ. If the index of the expansion curve is $n = 1.25$, the work expended per pound of air is

$$138550 \left[\rho^{0.2} - 1\right] \text{ foot lbs.}$$

Rise of Temperature during Compression.—For isothermal compression the temperature is constant. In any other case

$$T_1 = 521 \rho^{\frac{n-1}{n}}$$

For adiabatic compression substitute γ for n. The rise of temperature is considerable, as the following table shows:—

[1] Let $P_a V_a T_a$ correspond to the initial, and $P_1 V_1 T_1$ to the final, conditions in any compressor. Then

$$n = \frac{\log (P_1/P_a)}{\log (V_a/V_1)}$$

$$= \frac{\log (P_1/P_a)}{\log (P_1/P_a) + \log (T_a/T_1)}$$

$\frac{P_1}{P_a}$	P lbs. per sq. in. absolute	Temperature reached in compression		
		Isothermal $n=1$	Partially cooled $n=1.25$	Adiabatic $n=1.41$
2	29.4	60	137	176
3	44.1	60	187	255
4	58.8	60	226	318
5	73.5	60	256	370
6	88.2	60	284	415
7	102.9	60	307	455

Unnecessary Waste of Work in Heating the Air in the Compressor.—If the compressed air were used in a motor directly adjacent to the compressor, in its heated state, there would be no necessary loss due to rise of temperature during compression. Commonly the air is used at a distance, and has cooled from T_1 to atmospheric temperature T_a and shrunk in volume from BC to BF (fig. 47) before reaching the working point. The most economical compression for air transmission would be isothermal

FIG. 18.

quantity. Hence the curious result is arrived at that in the most economical compression, the effective work of compression is entirely abstracted as heat and wasted. All the compression does is to put the air in a condition to do work in a motor at the expense of its intrinsic energy. In that way there is obtained an amount of work nearly equal to the work done in compression. But the work in the motor is not strictly the restoration of the energy expended in the compressor, but energy borrowed from the air. Hence the conditions of transmission of power by compressed air are different from those of transmission by pressure water.

Case of Adiabatic Compression.—The volume of one pound of air at the final pressure P_1 will be

$$v_1 = v_a \left(\frac{P_a}{P_1}\right)^{\frac{1}{\gamma}} = 13.09 \left(\frac{P_a}{P_1}\right)^{0.71}$$

The absolute work of adiabatic compression is per pound of air

$$\frac{P_1 V_1 - P_a V_a}{\gamma - 1}.$$

Hence the effective work in one revolution of the compressor (ABGD, fig. 47) is

Compressed Air

Theodore Simons, 1st Edition, 1914
pages 113–123

CHAPTER XIII

EFFECT OF LOSS OF HEAT, GENERATED DURING COMPRESSION, ON THE ULTIMATE USEFUL ENERGY RESIDING IN A GIVEN QUANTITY OF COMPRESSED AIR

117. By an accepted law of thermodynamics, work and heat are mutually convertible at the ratio of about 778 ft.-lb. of work for every B.T.U.

In Article 41a it was stated that the work expended in compressing air is all converted into heat. According to the law quoted, we should expect the compressed, and therefore heated, air to be capable of performing useful work, equal to the amount expended in compressing it. Neglecting friction in the air engine, this would actually be the case, if the compressed air could be used immediately after compression and before it has lost any of its heat.

If, on the other hand, the compressed air be allowed to cool down to the temperature which it possessed before compression, as happens in all compressed air installations, it would seem logical, by applying the same law quoted above, to reason as follows:

Since the work of compression is all converted into heat, the ability for doing useful work must have disappeared after all this heat has been abstracted.

In the following articles it will be shown:

a. That the work of compression is all converted into heat.

b. That, after all the heat of compression has been abstracted, there still remains in the compressed air a certain amount of energy for doing useful work.

c. That this is due to the energy residing in the air before compression.

a. Referring to Fig. 17, the total work of compressing adiabatically a volume V_1 cubic feet of free air from an absolute pressure P_1 to an absolute pressure P_2 is represented by the area $MABR$. Expressed in foot-pounds, it is equal to 144 times the numerical value of this area.

In Article 44 we found:

$$\text{Area } MABR = \frac{P_2V_2 - P_1V_1}{n-1} \tag{1}$$

therefore, total work of compression

$$W_1 = 144\frac{P_2V_2 - P_1V_1}{n-1} \text{ foot-pounds.} \tag{2}$$

Let $P_1 = 14.7$ lb. absolute pressure per square inch.

$P_2 = 89.7$ lb. absolute pressure per square inch.

$\quad = 75$ lb. gage.

$V_1 = 13.09$ cu. ft. which is the volume of 1 lb. of free air at sea level and at 60° Fahr.

$n = 1.406.$
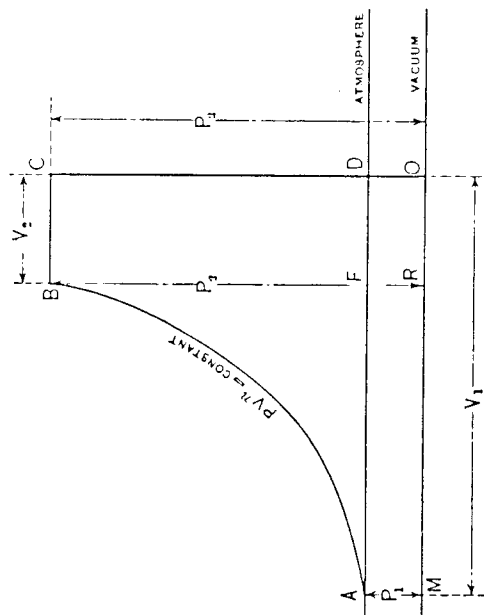
Fig. 17.

From equation (7), Article 41, deduce:

$$\frac{V_2}{V_1} = \left(\frac{P_1}{P_2}\right)^{\frac{1}{n}}$$

whence $V_2 = V_1\left(\frac{P_1}{P_2}\right)^{\frac{1}{n}} = 13.09\left(\frac{14.7}{89.7}\right)^{0.71} = 3.62$ cu. ft. $\quad(3)$

Substituting values in equation (2) we get:

$$W_1 = 144\frac{89.7\times3.62 - 14.7\times13.09}{0.406} = 47,000 \text{ ft.-lb.} \tag{4}$$

After the air has been compressed adiabatically to an absolute pressure P_2 its absolute temperature will be according to equation (11), Article 41:

$$T_2 = T_1\left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}} = (60+461)\left(\frac{89.7}{14.7}\right)^{0.29} = 880° \text{ absolute} \quad (5)$$
$$= 419° \text{ Fahr.}$$

After compression, the original pound of air occupies a volume $V_2 = 3.62$ cu. ft. and has a temperature of 419° Fahr. which is $(419-60) = 359$ degrees more than its initial temperature.

Now, we can imagine a volume V_2 of air weighing 1 lb. to have a temperature of 60° Fahr. If we raise the temperature of this air by $(T_2 - T_1) = (880 - 561) = 359$ degrees without changing its volume, we heat under constant volume. The specific heat C_v of air in this case is 0.168 and the amount of heat put into this pound of air, expressed in B.T.U.'s, is

$$C_v(T_2 - T_1) = 0.168 \times 359 = 60.3 \text{ B.T.U.'s.}$$

Expressed in foot-pounds it is:

$$K_v(T_2 - T_1) = 131.6 \times 359 = 47,000 \text{ ft.-lb.} \quad (6)$$

A comparison of equation (6) with (4) shows that the mechanical equivalent of the heat required to raise the temperature of 1 lb. of air from an absolute temperature T_1 to an absolute temperature T_2 is identical with the mechanical energy expended in compressing adiabatically 1 lb. of atmospheric air having an absolute temperature T_1 to a pressure which raises the temperature of the air to an absolute temperature T_2. In other words, the mechanical work of compressing air adiabatically is all converted into heat energy.

b. If we now allow this volume $V_2 = 3.62$ cu. ft. of compressed air, having a temperature of 419° Fahr., to cool down to initial temperature of 60° Fahr. under constant volume, its pressure will decrease to a pressure P_3, which we find from the formula:

$$P_3 = P_2\frac{T_3}{T_2} = 89.7 \times \frac{521}{880} = 53.2 \text{ lb. absolute.}$$

The energy residing in this volume $V_3 = 3.62$ cu. ft. of air for doing useful work in expanding adiabatically down from an absolute pressure of 53.2 lb. to atmospheric pressure is represented by the area $BCGF$ in the diagram, Fig. 18, and expressed in foot-pounds it is 144 times the numerical value of this area. From article 110 we deduce:

$$\text{Area } BCGF = \frac{P_3V_2 - P_1V_1}{n-1}$$

Hence energy $$W = 144\frac{P_3V_2 - P_1V_1}{n-1}$$
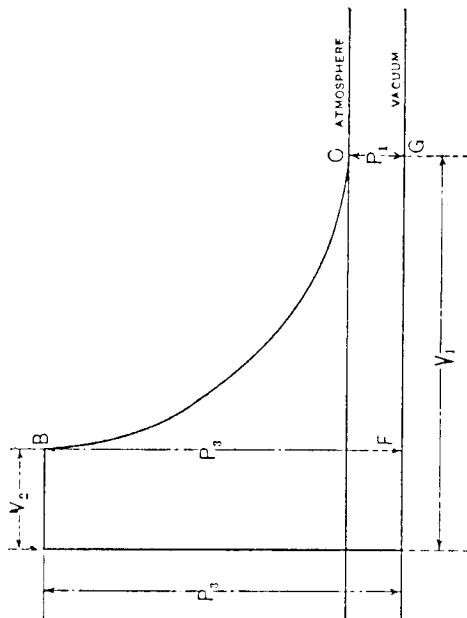
FIG. 18.

Applying it to the case in hand:

$P_3 = 53.2$ lb. absolute per sq. in.
$V_2 = 3.62$ cu. ft.
$P_1 = 14.7$ lb. per sq. in.

$$V_1 = V_2\left(\frac{P_3}{P_1}\right)^{\frac{1}{n}} = 3.62\left(\frac{53.2}{14.7}\right)^{0.71} = 9.02 \text{ cu. ft.} \quad \text{(From equation 13, Article 41.)}$$
$$n = 1.406.$$

Hence $$W = 144 \times \frac{53.2 \times 3.62 - 14.7 \times 9.02}{0.406} = 21,300 \text{ ft.-lb.}$$

Comparing this with the work of compression, we have:

$$\frac{21,300}{47,000} = 0.45 = 45 \text{ per cent.}$$

That is, theoretically, after cooling down to initial temperature, there still remains in the compressed air energy for doing expansive work to the amount of 45 per cent. of the energy expended in compressing it.

Referring to the diagram in Fig. 17, it will be noted that part of the total work of compression represented by the area *MABR* is performed by the atmospheric air rushing into the cylinder behind the piston during the compression stroke and not by energy furnished by the compressor. This work is represented by the area *MAFR*.

In practice, the air, after being compressed, is delivered into the receiver. The work of delivery is jointly performed by the compressor and by the atmospheric air. The compressor's work is represented by the area *FBCD* and the work of the atmosphere by the area *RFDO*. The net work of compression and delivery done by the air compressor alone is represented by the area *ABCD*. The compressor's share of delivery work is always available for doing useful work in the air engine because in forcing a volume of compressed air from the air-cylinder into the receiver, an equal volume of air is displaced therein, and this displacement process is extended into the pipe line and finally into the air engine, where, in making room for itself, this volume of compressed air drives the piston forward, and thus does useful work.

It may be asked: What becomes of the energy contributed by the atmospheric air toward compression and delivery which is represented by the area *MADO* in Fig. 17?

This energy is actually stored up in the compressed air when the latter leaves the compressor. It could do useful work if it were practicable to exhaust the air from the engines into a vacuum. But since we must exhaust against atmospheric pressure, the energy is consumed in the process of exhaustion and is therefore not available for useful work. It is not included in the formulas expressing power to be furnished by the compressor because it is furnished gratis by the atmosphere; and it is not included in the formulas expressing the useful work which a volume of compressed air can perform, because it is not available for such work.

The following example shows the effect of heat loss upon the total power stored up in a mass of air by the compressor.

Example.—To compress adiabatically in one stage 100 cu. ft. of free air per minute at sea level to 60 lb. gage and deliver it into the receiver, requires (theoretically) 13.40 h.p. (from column 4 Table V).

If the temperature of the free air was 60° before compression, after compression it will be 375° Fahr. (column 6 Table V) and the volume of the compressed air will be 31.44 cu. ft. (column 5 Table III)

If used immediately after compression, before having lost any heat, it could do work (theoretically) to the amount of 13.40 h.p. by expanding adiabatically down to atmospheric pressure.

But if allowed to cool, before use, to initial temperature under constant volume, the pressure will decrease to a pressure P_3 which we find from the following formula:

$$P_3 = P_2 \frac{T_3}{T_2} = (60+14.7)\frac{60+461}{375+461} = 46.6 \text{ lb. absolute.}$$

A volume of 31.44 cu. ft. of air per minute at 46.6 lb. absolute, if allowed to expand adiabatically down to atmospheric pressure could perform (theoretically) an amount of work found from equation (1) Article 111:

$$\text{Horse-power} = \frac{144\,n\,P_2 V_2}{33,000\,(n-1)}\left[1-\left(\frac{P_a}{P_2}\right)^{\frac{n-1}{n}}\right]$$

$$= \frac{144\times1.406\times46.6\times31.44}{33,000\times0.406}\left[1-\left(\frac{14.7}{46.6}\right)^{0.29}\right] = 6.30 \text{ h.p.}$$

which is about 47 per cent. of the power expended in compression and delivery.

When friction and other imperfections are taken into account, this percentage decreases materially.

Adding 15 per cent. to the power of production we get 15.43 h.p.

Subtracting 15 per cent. from the available theoretical energy we get 5.35 h.p. and the comparative value shrinks to 35 per cent. This is further diminished by losses during transmission which are pointed out under Articles 93–94 and 97–105.

c. The answer to the question, why energy still remains in the compressed air after all the heat of compression has been dissipated, is that a certain capacity for work resides in the air which is due to the latter's ability to expand when the proper conditions prevail.

Such conditions could be brought about by confining a volume of atmospheric air in a cylinder under a piston and then create a partial vacuum on the other side of the piston; the atmospheric air in the cylinder would expand and push out the piston, that is, perform work. But creating a vacuum requires extra work, and is therefore not of practical application in air engines.

As a matter of fact, after all the heat generated during compression of a volume of air has been dissipated, the compressed air possesses no more energy than it did before compression, but the

energy which it did possess has, by mechanical compression, been made available for doing useful work.

To do work, however, the air requires energy in the form of heat and while expanding, it consumes heat that was contained in its mass before compression. As a consequence the temperature of the expanded air falls below that of the surrounding atmosphere. The amount of heat consumed is equivalent to the amount of work performed and equal to the amount of heat that would be generated in compressing this air from the pressure at which it exhausts from the air engine to the pressure at which it enters the same.

The consumption of heat from the mass of the expanding air is manifested by the cold created in and around the cylinders of an engine using air expansively. Theoretically this is exactly the reverse of the generation of heat in the air cylinders of a compressor.

117a. Determination of the Value of "n," used in adiabatic compression and expansion formulas:

From equation (6), Article 117, we have:
Work of adiabatic compression of 1 lb. of free air:

$$W = K_v(T_2 - T_1) \text{ foot-pounds} \quad (1)$$

in which K_v = specific heat of air at constant volume, expressed in foot-pounds.

T_2 = final absolute temperature of air after being compressed to an absolute pressure P_2.

T_1 = initial absolute temperature of air at an absolute pressure P_1.

In the diagram, Fig. 17, the area $MABR$ represents the mechanical work of compressing a volume V_1 of air from an absolute pressure P_1 to an absolute pressure P_2, the volume of compressed air being V_2.

From equation (1) Article 117:

$$\text{Area } MABR = \frac{P_2V_2 - P_1V_1}{n-1} \quad (2)$$

Let P_1 and P_2 be the absolute pressures in pounds per square foot; then the work performed, corresponding to area $MABR$:

$$W = \frac{P_2V_2 - P_1V_1}{n-1} \text{ foot-pounds} \quad (3)$$

Let, furthermore, V_1 and V_2 represent volumes occupied by 1 lb. of air when under an absolute pressure of P_1 or P_2 respectively; then from equation (5) Article 20:

$$P_1V_1 = RT_1$$
$$P_2V_2 = RT_2$$

and

Substituting these values in equation (3) we have:

$$W = \frac{RT_2 - RT_1}{n-1} = \frac{R(T_2 - T_1)}{n-1} \quad (4)$$

From equation (7) Article 20 we have:

$$R = K_p - K_v$$

Substituting in equation (4) we get:

$$W = \frac{(K_p - K_v)(T_2 - T_1)}{n-1} \quad (5)$$

This work is equal to the work expressed by equation (1), therefore:

$$K_v(T_2 - T_1) = \frac{(K_p - K_v)(T_2 - T_1)}{n-1}$$

or

$$nK_v - K_v = K_p - K_v$$

whence

$$n = \frac{K_p}{K_v} \quad (6)$$

as first stated under Article 40.

CHAPTER XIV

INTERNAL OR INTRINSIC ENERGY OF AIR

118. A capacity for doing useful work by expanding against an external resistance, resides in a mass of air as long as its temperature is above the absolute zero. A pound of atmospheric air, for instance, may be conceived as the outcome of a pound of air at the temperature of absolute zero to which a sufficient amount of heat has been supplied to raise its temperature by (461 + 60) = 521° Fahr., and its pressure to 14.7 lb. above the vacuum.

According to a law of thermodynamics, quoted in previous articles, the heat energy in this pound of air, corresponding to a temperature of 521° above the absolute zero, may be converted

into mechanical energy whenever the conditions permit it. The capacity of air of performing work, due to its temperature above the absolute zero, is called *the internal or intrinsic energy of air.*

It is independent of pressure, that is, a pound of atmospheric air at a temperature of 60° Fahr., has the same intrinsic energy as a pound of air under a pressure of 100 lb. having the same temperature of 60° Fahr. (See Articles 119 and 120.)

When applied to practice, there is a vast difference, however, between the pound of atmospheric air and the pound of air at 100 lb. pressure. In the first case none of the intrinsic energy residing in the air is available for useful work under ordinary conditions, whereas in the second case a portion of the intrinsic energy has by mechanical compression been made available for such work.

This may be better understood by comparison with the more familiar generation of water-power. Water flowing down a river possesses intrinsic energy, that is, a capacity for doing useful work when the proper conditions exist. These conditions are brought about by building a dam across the river which raises the water level and thus produces a head, the height of which, together with the amount of water delivered, determines the amount of useful work the water is capable of performing. By building the dam we have added nothing to the intrinsic energy of the water, we have only made available a portion of that energy for performing useful work.

In an analogous manner, by compressing air isothermally, we add nothing to its intrinsic energy, we merely make a portion of that energy available for doing useful work. In actual practice, compression is more or less adiabatic, imparting heat energy to the air, which, however, is subsequently lost in transmission. The condition of the air before use is therefore the same as after isothermal compression.

The conception of internal or intrinsic energy indicates that when air expands without doing work, it loses none of its heat, because the intrinsic energy remains unchanged. The truth of this fact was first proved experimentally by Joule and the fact itself is known as Joule's Law.

119. Intrinsic Energy of a Pound of Atmospheric Air at a Temperature of 60° Fahr.—The specific heat of air under constant pressure is 0.2375, therefore the quantity of heat, that is, the number of B.T.U.'s required to raise the temperature of 1 lb. of atmospheric air from absolute zero to 60° Fahr. is:

$$(461 + 60) \times 0.2375 = 123.74 \text{ B.T.U.'s}$$

and the amount of work corresponding to this quantity of heat is $123.74 \times 778 = 96,268$ ft.-lb. This is the intrinsic energy of 1 lb. of atmospheric air at 60° Fahr., none of which, however, is available for useful work under ordinary circumstances.

120. Intrinsic Energy of a Pound of Air at 100 lb. Gage and at 60° Fahr.—If permitted to expand adiabatically down to atmospheric pressure against an external resistance, this pound of air would perform work and therefore consume an amount of heat equal to the amount that was generated during adiabatic compression. The theoretical temperature of the air after expansion is deduced from formula (11) Article 41:

$$T_1 = T\left(\frac{P_1}{P}\right)^{\frac{n-1}{n}} = (60+461)\left(\frac{14.7}{100+14.7}\right)^{0.29}$$

$$= 286.55 \text{ degrees absolute.}$$
$$= -174.45° \text{ Fahr.}$$

The drop in temperature is therefore $(60 + 174.45) = 234.45$ degrees and the number of B.T.U.'s consumed during expansion would be $234.45 \times 0.2375 = 55.68$ B.T.U.'s.

The equivalent of 55.68 B.T.U.'s expressed in foot-pounds is $55.68 \times 778 = 43,321$ ft.-lb. This is the amount of intrinsic energy residing in the pound of compressed air which is available for doing useful work.

But there still remains energy in the air which might be used if it were possible for the air to expand down to the absolute zero of pressure, in which case the temperature of the air would drop from 286.55 absolute to the absolute zero of temperature. This represents a loss of heat units equivalent to $(286.55 \times 0.2375) = 68.065$ B.T.U.'s and these 68.056 B.T.U.'s present work equivalent to $(68.056 \times 778) = 52,947$ ft.-lb. This latter energy is not available for useful work under ordinary circumstances.

The total intrinsic energy of the pound of air at 100 lb. gage and 60° Fahr. is $(43,321 + 52,947) = 96,268$ ft.-lb. which is the same as the total intrinsic energy of the pound of atmospheric air at 60° Fahr.

As evidenced by the excerpt below, it is no longer common knowledge among those who teach compressed air practice that all the compressor's work is wasted as heat, leaving behind in the cooled compressed air no source of usable energy other than the internal energy that was already in the air--in a nonusable form-- before it was compressed. Because this fact, like many other facts about compressed air, is no longer taught, engineers react with complete skepticism upon hearing it. It is assumed that most of the compressor's energy is wasted as heat, with the rest of it represented by the energy available in the pressurized condition of the air. If Simons and Unwin (above) are wrong, then I would like to know what's wrong with their math and or logic, since the compressed air formulas used today are the same ones used by Simons and Unwin. If Talbott (below) is right when he states that only 60-90% of the compressor's work turns into heat, then why doesn't he show his math? Did he use formulas, or is he only repeating an assumption that has been passed down ever since the textbooks were cleaned up in 1931?

E.M. Talbott. Compressed Air Systems: A Guidebook on Energy and Cost Savings. Atlanta: Fairmont Press, 1986. 77-79.

4.1.5 Heat Recovery

Adiabatic compression of air to 100 psi results in outlet air temperatures of 350 - 500°F. When this air is cooled to ambient temperatures, 60 - 90 percent of the energy of compression is removed, and this can be used for other purposes. This heat is a low grade source that is available year round whenever the plant is in operation. Typical uses of the air include supplemental space heating, boiler makeup water preheating, or process heating.

If a regular all season use of this low grade heat source is available, the heat recovery system efficiency considerations are of greater importance than the compressor efficiencies discussed in section 4.1. Since nearly 80% of the input energy is available as heat, the 20% energy content of the compressed air is nearly a by-product. In multiple compressor systems, the compressors could be located near each of the locations requiring space heating to minimize the ducting requirements, air pressure control stability considerations permitting.

Proposal for the Use of a Controlled Tornado-like
Vortex to Capture the Mechanical Energy Produced
in the Atmosphere from Solar Energy

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Abstract

The energy of the wind could be harnessed by controlling
the atmospheric process so that wind energy is released at
high intensity at selected locations. An engine consisting of
a controlled tornado-like vortex is proposed.

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1. Apparatus for generating electric power from atmo-
spheric wind comprising: a generally tubular shaped, open
ended tower structure, including means for selectively admit-
ting wind into said tower along a substantial vertical length
thereof, the interior surface of said tower defining a convolute
chamber to cause said admitted wind to flow in a vortex flow
regime having a low pressure core; means for permitting atmo-
spheric air to be drawn into the bottom of said tower and
accelerated by the core; turbo machine means located at the
lower end of said tower structure and adapted to be driven by
the air drawn in through the bottom of the tower.

10. Apparatus for generating electric power from atmo-
spheric wind comprising: an open ended, tower structure
including a plurality of generally vertically extending vanes,
said vanes forming a substantial portion of the vertical height
of said tower structure; means for rotatably mounting each of
said vanes; means for sensing the direction of said atmospheric
wind; control means operatively coupled to said sensing means
for opening the vanes facing in the direction of said wind to
admit said wind into said tower, the interior surface of said
tower defining a convolute chamber to cause said admitted
wind to flow in a vortex flow regime having a low pressure
core; means for supporting said tower in spaced relationship
from ground; and turbomachine means including a generator
and a turbine blade assembly adapted and arranged to rotate in
a horizontal plane and drive said generator, said assembly
being located within said tower adjacent the lower end
thereof, said assembly being adapted to be driven by air drawn
into said low pressure core.

Mechanical energy, the kinetic energy of the wind, is pro-
duced in the atmosphere because the atmosphere is an en-
gine where solar radiation is partly transformed into
mechanical energy. Solar energy is received at low intensity
but the mechanical energy produced in the atmosphere from
solar radiation is occasionally released at high intensity.
The existence of storms and particularly of tornadoes proves
that low intensity solar radiation can result in high in-
tensity mechanical energy.

The mechanical energy is produced where the heated air
rises and expands and not necessarily where the solar radia-
tion is received. It is proposed to capture the mechanical
energy produced in the atmosphere by forcing the expansion

to take place at a selected location by means of a controlled vortex similar to a natural tornado.

The vortex would be established above a station consisting of a ring of deflectors. The proposed vortex power station is shown in Fig. 1. The vortex would be started by heating the air within the station with fuel. Once started, the vortex would persist without further heating with fuel because the air at the bottom of the atmosphere is heated by solar radiation. Some of the mechanical energy produced by the expansion of the rising air would be harnessed by expanding some of the air surrounding the station into the low pressure zone produced by the vortex via turbines installed under the deflectors. The station would be 100 to 1000 m in diameter.

Mechanical energy is produced when heat is convected upward. Conditionally unstable air is in a metastable state in the sense that when it is lifted sufficiently it becomes less dense than ambient air, and then continues to rise from its own buoyancy. It is well known that warm rising air is diluted by the air through which it rises and that this is a factor which inhibits convective heat transport. One might use a large chimney to prevent rising air from being diluted by ambient air. An upward flow could be established in a large chimney by heating the air within the chimney with fuel. The upward flow in the chimney would persist after the heating with fuel stops when conditional instability exists.

The use of a large chimney to promote convection and to produce precipitation is an old meteorological concept. Recently Starr et al. (1974) proposed the use of a vertical tube called an aerological accelerator to produce precipitation. Lev (1951) has described a proposal by Dubos in 1925 of a power station involving a large chimney.
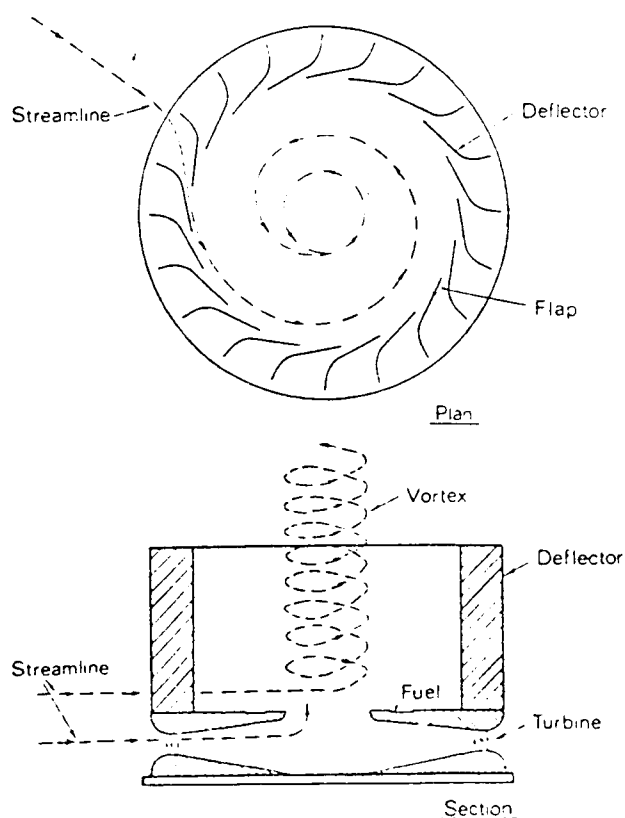
The operation of a natural draft chimney depends on the fact that a chimney is a cylinder in radial compression which prevents convergence in the horizontal plane in spite of the fact that at any given level the pressure is less inside than outside. The puffy appearance of hot smoke coming out of a chimney shows how rapid is the ingress of ambient air into the rising smoke once the protection provided by the chimney stops. A solid chimney could be replaced by a cylinder of air rotating about the vertical axis. The centrifugal force produced by the rotation of a mass of air can prevent horizontal convergence just as well as the solid wall of a chimney.

Tornadoes, water-spouts, and dust devils are rising currents of air which rotate about the vertical axis as they rise and which owe their existence partly to centrifugal force preventing dilution. The reason why the air that rises in a tornado rotates is that when the air which is at the bottom of the atmosphere converges, its angular velocity must increase to conserve angular momentum. And the reason why the air converges towards one point is that at this point there is a vortex chimney.

It is proposed to produce a controlled atmospheric vortex above a station consisting of a ring of deflectors. The station could be as shown in Fig. 1, the lower section containing the turbines is not essential. The deflectors could be similar in construction to aircraft wings. The vortex would be started by burning some fuel on the bottom of the station. The air within the station would rise as a result of the heating, and the air surrounding the station would converge towards the center of the station to replace the rising air. The converging air would acquire angular momentum when it passes between the deflectors, and as it continued to flow towards the center of the station its angular velocity would increase to conserve the acquired angular momentum. This air would rotate when it rises and centrifugal force would prevent its dilution by the air through which it rises. Once established, the vortex should persist after the heating with fuel has stopped, and should remain inside the station; provided that the station is large enough, that the atmosphere is sufficiently unstable, and that the horizontal wind is not excessive.

I verified part of the hypothesis on a small model in my back yard. I produced vortices that looked like small tornadoes by burning some fuel spread on the ground inside a circle of deflectors. See Fig. 2. These vortices did not persist after the heating with fuel stopped because the tests were on too small a scale. The largest test was done with deflectors 1 m high placed on a circle 1.5 m in diameter. The largest vortex produced was approximately 10 m high by 0.1 m in diameter.

Substituting high intensity heating with fuel for low intensity solar heating makes it possible to produce vortices using a small station. The fact that a given quantity of fuel burned much more rapidly and completely with deflectors than without deflectors was interpreted as proof that a vortex has an effect similar to that of a chimney.

The tests indicated that the base of the vortex would remain in the center of the station. A ring of fuel outside the ring of deflectors was ignited just before the fuel inside the ring of deflectors burned out, and the vortex remained in the center of the ring of deflectors even after the fuel inside the ring of deflectors had burned out.

The thermodynamic cycle of the proposed process is shown in Fig. 3. For the purpose of thermodynamic calcula-

FIG. 1. Vortex power station.

The effect of irreversibilities can be investigated by replacing the turbine with a restriction where an amount of irreversible work to heat reversion equal to the net cycle work takes place. The restriction can be lumped or distributed around the cycle to investigate various effects. An interesting feature of the cycle is that the net cycle work is released at the point where there is the most resistance to flow; the turbine could be located anywhere around the circuit.

The efficiency of a Carnot engine transferring heat from a temperature of 15°C at the bottom of the troposphere to a temperature of −50°C at the top of the troposphere would be 23%. According to Gray (1973) the convective heat flux is a maximum at the bottom of the troposphere and gradually decreases to zero at the top of the troposphere. Taking the average temperature of the cold source as −15°C, the amount of mechanical energy produced in the atmosphere is 10% of the convective heat flux at the bottom of the atmosphere. Taking the average upward convective heat flux, both sensible and latent, at the bottom of the atmosphere as 100 W/m², the amount of mechanical energy produced in the atmosphere is 10 W/m². Kung (1966) calculated that the amount of mechanical energy that must be produced to support large scale circulation is 7 W/m². Based on the value of 10 W/m², the amount of mechanical energy produced for an area of 1000 km² is 10 000 MW. The fact that large quantities of mechanical energy are produced is recognized; capturing this energy is the problem.

Starr et al. (1974) have concluded that an aerological accelerator cannot supply a significant amount of power. Starr's conclusion is based on the fact that the kinetic energy of the air leaving the top of the tube is lost. This conclusion is valid for an aerological accelerator but not for a vortex. There is a zone of divergence at the top of a vortex where the vertical velocity of the air reduces to zero and where the kinetic energy of the air is recovered. A similar effect could be obtained by flaring the top of the aerological accelerator, a technique commonly used to reduce exit losses.

Starr et al. used the following equation:

Fic. 2. Vortex produced by burning fuel inside a circle of deflectors.

tions the cycle can be considered independently of the atmospheric process. The cycle is very similar to the standard gas turbine power cycle. The gas is compressed by being lowered instead of in a conventional compressor, and the work of compression is supplied directly by the work of expansion. The pressure differential across the turbine results from the difference in weight between a column of cooled gas and a column of uncooled gas. A standard gas turbine power cycle cannot operate across a small temperature differential because of the low efficiency of mechanical compressors, but using gravity to compress a gas as it is lowered is very efficient, so that the cycle is practical for small temperature differentials. The engine must be several kilometers high to achieve even a small temperature differential.

Cycle calculations are carried out by applying the energy balance equation in the following form to each process of the cycle (see list of symbols at end of note):

$$Q - W_s = \Delta H + \Delta g z + \Delta v^2/2. \tag{1}$$

The calculations show that if the cycle is assumed to be reversible the net cycle work is equal to the work that would be produced if the heat transfer was accomplished via Carnot engines, irrespective of the quantity of heat transported per unit mass of air and irrespective of whether the heat is transported as sensible or latent heat.

$$gL \frac{(\rho_r - \rho)}{\rho_t} = \frac{2L}{R} \frac{\rho}{\rho_t} C_{D} u^2 + u_t^2. \tag{2}$$

Fic. 3. Vertical power cycle.

The left hand term represents the energy available from buoyancy forces, the first term on the right represents the energy required to overcome viscous friction in the tube, and the second term on the right represents the kinetic energy of the air leaving at the top of the tube. When the effect of divergence at the top of the vortex and the consequent reduction in vertical velocity is considered the last term drops out of the equation.

The effect of dropping the last term plus the increase in height and diameter possible with a vortex can increase the amount of energy released from 5 MW calculated by Starr *et al.* to several thousand megawatts. A further effect of vortex flow is that centrifugal force prevents the flow from becoming turbulent even though the Reynolds number is high. At high Reynolds numbers the value of the friction factor, C_D, is much lowe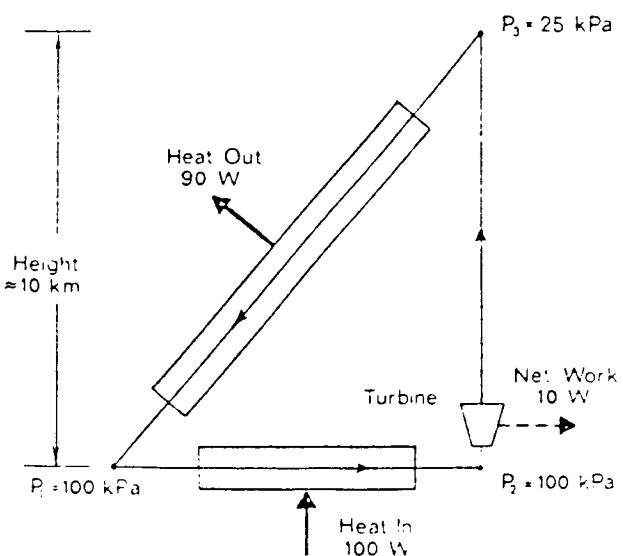r for laminar flow than for turbulent flow. The value of the friction factor could therefore be two orders of magnitude less for a vortex than for a tube. This reduction in friction factor plus the increase in diameter with height would further increase the amount of mechanical energy that can be produced

The differential pressure developed at the base of a tornado indicates that only a small amount of the energy released is required to overcome friction in the tube. Most of the energy released is required to overcome the resistance to the flow of converging air at the base of the vortex because convergence is only possible in approximately the bottom 10 m of the atmosphere where friction reduces the angular momentum of the converging air. As far as resistance to flow is concerned, a tornado 50 m in diameter at the base may be equivalent to a vertical tube 10 km high by 0.5 km in diameter at the base and 5 km in diameter at the top, with a passage only 10 m high between the bottom of the tube and the Earth's surface.

In the proposed engine the turbine is effectively placed in parallel with the point of the cycle where there is the greatest resistance to flow. It is expected that it will be possible to extract energy with the turbines without excessively reducing the intensity of the vortex because with a vortex station it is possible to raise the base of the vortex and to reduce the amount of energy dissipated in the convergence zone. For the same reason it may be possible to sustain a vortex when atmospheric conditions are less unstable than found in tornadoes.

An atmospheric vortex must have a minimum size to be self sustaining because the air at the bottom of the atmosphere must be lifted enough to become appreciably less dense than the overlying air, and because the amount of energy required to overcome viscous friction per unit mass of flow decreases with size. I estimate that it would be possible to produce a self sustaining vortex with a station 10 m in diameter, under optimum conditions, when instability is pronounced. A power station would have to be 100 to 1000 m in diameter. The deflectors could be 20 to 100 m high. The capacity of the station could be 1000 MW of mechanical energy. There could be 400 turbines of 2.5 MW capacity by 10 m in diameter around the perimeter of the depression chamber. The turbines could be similar in construction to aircraft propellers. The pressure differential across the turbines could be from 0.01 to 10 kPa. Heating with fuel for 5 min would be sufficient to establish the vortex. The diameter of the vortex and the quantity of air flowing could be controlled by adjusting flaps on the tips of the deflectors. Increasing the amount of deflection and the amount of

jetting between the deflectors would increase the diameter of the vortex. There might be locations where it would be possible to operate such a power station most of the time.

The use of a circle of deflectors to produce a vortex and to promote convection and precipitation was proposed by Dessoliers (1913). He proposed to use a black heat absorbing surface to start the vortex. In the 1950s H. Dessens, as reported by J. Dessens (1962, 1969), produced tornado-like vortices over 1 km high by using gas burners oriented tangentially on the arms of a spiral. H. Dessens was attempting to produce convection and precipitation by the use of heat; he did not use deflectors; the vortex formed downwind of the heating device. Recently, Nazare (1973) proposed a 1000 MW power station consisting of a 600 m high chimney similar to a natural draft cooling tower, with a large turbine at the throat. He proposed using deflectors in his tower to produce a cyclone.

More extensive study of feasibility of the proposal and of many related problems is required. There might be beneficial uses for this process other than the production of energy. The process could be used to produce precipitation or to otherwise influence weather. The possibility that adverse weather conditions might be created would have to be considered.

It is generally recognized that the amount of energy produced by man is small compared to the amount of energy produced in storms. Based on an average of 10 W/m² the amount of mechanical energy produced in the atmosphere is 5100 TW. The total amount of energy produced by man is 10 TW. Control of the atmospheric engine could make the vast amount of mechanical energy being produced in the atmosphere available to do useful work. Weather control is a potential source of energy.

The calculations on which this proposal is based are given in a companion manuscript (Michaud, 1974) oriented toward the engineering community.

Definition of Symbols

Q	heat (kJ/kg)
W/s	shaft work (kJ/kg)
H	enthalpy (kJ/kg)
g	acceleration of gravity (9.8 m/s²)
z	elevation (m)
v	velocity (m/s)
L	height of tube (m)
ρ_*	average density of environment (kg/m³)
ρ	average density in tube (kg/m³)
ρ_t	density at top of the tube (kg/m³)
R	radius of the tube (m)
C_D	friction factor (dimensionless)
w	average vertical velocity in tube (m/s)
w_t	vertical velocity at top of the tube (m/s)

ARE SOLAR HEAT PUMPS THE FUTURE IN HOME HEAT?

By Philip L. Harrison

IN AN AGE where the price of energy seems to be going through every roof, it's little wonder that homeowners are seeking cheaper ways to keep the home warm. It's little wonder, too, that the heat pump business is getting hotter all the time. Heat pumps, because of their high efficiency over, say, electrical resistance heating, can offer an average saving of 45 percent, depending on where you make your abode.

Solar heating, too, is tempting, but technology has not made it a practical proposition for much of the country. Until now, that is.

Now the race is underway to team the heat pump with solar collectors. The combination could just possibly develop into one of the most efficient home heating systems ever.

A top-of-the-line standard heat pump might have an average COP rating of 2.5, which means that for every BTU of electrical energy going into the unit, you get 2.5 BTUs of heat out.

But there are efficiency problems. As the outside temperature falls, the COP of the heat pump also falls. This is because the evaporator's temperature must always be colder than the outside air. In other words, just when you need it most, the heat pump starts costing more to operate. That's where the solar connection comes in.

The system that is sure to shake up the market a bit is Fedders' *Carnot II Solar Compression Furnace*. Named for French physicist Nicolas Leonard Sadi Carnot, the Carnot II replaces the heat pump's usual reciprocating compressor with a rotary one. The result is an impressive drop in compressor electrical energy consumption.

Solar-heated water in the system is pumped from a storage tank into Carnot II, where it enters a coaxial counterflow evaporator. In this evaporator, warm water flows in one direction through an inner tube while cold Freon vapor circulates through the outer tube in the oppo-

site direction.

Heat is transferred to the Freon, which is then drawn into the rotary compressor and pressurized. The temperature is raised to as much as 175°F. In the condenser, which also has a coaxial counterflow design, the Freon sheds the heat into a closed water circuit serving a fan-forced hydronic heating coil. The resulting warm air is then ducted to the house.

High-cost, high-efficiency solar collectors are not required and, in some areas of the country, could prove to be a detriment with the Carnot II.

Fedders will sell the Carnot II with or without collectors, so if you already have water collectors on your roof, the Carnot II can be retrofitted to them.

What does all this mean in terms of efficiency? An optimum COP of 12, with an average of around 7. You read it right. For every BTU in, you get seven out.

Installations placed in the chilly town of Caribou, Maine, on the Canadian border, rated an average COP of 5.56, which is more than double the average COP of the best standard heat pumps currently available. Albuquerque installations averaged 9.2 and those in Kansas City, 8.8.

Heat Pumps: Off and Running . . . Again

Leon R. Glicksman

Heat pumps appear to defy the law of energy conservation by producing thermal output two to three times greater than their mechanical input. But public unfamiliarity and the poor performance of some early models hamper their acceptance.

Fully half of the energy used in the residential and commercial sectors of the U.S. economy goes for space heating: one-sixth of total U.S. energy use, and one-fourth of our total oil and natural gas consumption. The sheer size of this energy demand establishes residential and commercial space heating as a fertile field for new or improved technologies that may increase the efficiency of energy use. The inefficiency of current space conditioning apparatus adds incentive to the effort.

The Two-Pipe System of Air Compression.

A CONSIDERATION OF THE ADVANTAGES CLAIMED FOR IT OVER THE SINGLE PIPE SYSTEM.

By A. E. CHODZKO.

There is nothing abnormal to an efficiency greater than 1, when reheating is used; this will occur (regardless of pipe and other friction) whenever the temperature of reheating is higher than the temperature of compression.

Springfield Men Invent Vehicle That Runs Only On Air

By TED BLACKMAN

SPRINGFIELD (UPI) — For years the dream of science fiction writers has been the vehicle that would run on some cheap, universally available fuel.

Something like air, for example.

A ridiculous notion, of course except for two Springfield men, who have actually built and driven a van which uses nothing but air as its primary fuel.

Ridiculous? I m p o s s i b l e? That's the reaction John Lunsford and Steve Hudspeth have faced. But they've managed to prove their case for the air-driven engine well enough to get two patents on the air-fuel processes they invented to drive a standard van.

"The patent attorney called it an 'air pulsing system,' " Lunsford of 1061 B St., said.

Hudspeth, described the basic process as a "compressed air amplifier."

The Engine

Inside the van, a complex-looking maze of tubes and pipes connect three cylinders to a 50-horsepower Cyclone engine. The engine has five cylinders and is called a "radial."

It's the old-fashioned radial engine, the sort World War I biplanes sported with the cylinders arranged around the crankshaft.

A difference: The engine is hydraulic. Its pistons are forced back and forth by air pressure instead of an exploding mixture of air and gas.

This is where the compressed air and the three "amplifiers" come in.

It's also where an ingenious system the two designed to take advantage of the condition of many Springfield streets comes into play.

First, compressed air from an ordinary tank just like those available at welding supply shops passed through electrically timed valves into the amplifiers.

Forces Pistons

The air rushes into the top of the amplifier cylinders, forcing pistons down. As this happens, air in the bottom of the cylinders is also compressed, thus adding to the volume of compressed air available to power the motor.

Still more compressed air is provided from the motor itself: As air passes through the radial cylinders, it is exhausted back to the amplifiers. In effect, the engine recycles its own exhaust which is only the same fresh air that powered it in the first place.

Even Springfield's r o u g h streets can help power the vehicle. Lunsford and Hudspeth designed a hydraulic pump system to replace the van's shock absorbers. As the car bumps over rough spots in the road, its lunging weight compresses still more air.

That air is fed into the amplifying system and on to the motor.

Besides compressed air, the system needs only a standard car and ordinary V-8 engine, Lunsford asserted.

Speed Lacking

isting system. "We've got it geared down so much, it'll only go 12-15 miles an hour," Lunsford said, "We didn't want to take a chance on losing power."

The men haven't done any mileage tests yet, either. "We have some air leaks in our system, so the tests really would not prove much," Lunsford noted.

They point out that their system could easily be more efficient than proposed electric cars with their tons of batteries required for even short trips. "And it's much easier to switch tanks of air than to recharge all those batteries," Hudspeth chuckled.

Now that both the air amplifiers and the hydraulic shock system have received patents, the two are working on ways either to get money to develop the compressed-air d r i v e scheme themselves or, if forced to, to let someone else do the engineering and development so it can be mass produced.

"I even took night classes at the university so I could learn something about how to sell it," said Hudspeth, who is an electrician for Rosboro Lumber Co.

Lunsford is a millwright for Cone Lumber Co., in Goshen.

ABOVE for Weekend Editions

Super Steam Making Machine Eliminates Need for Boilers

A technology is available that can effectively eliminate any need for using natural gas to heat water, homes or industry. It is a machine that can solve many of the energy problems which became go glaringly apparent last winter.

The device is a steam generating machine invented by the late Karl Schaeffer of Chicago. Schaeffer's method of making super-heated steam is instantaneous and will economically eliminate all need for huge boilers and direct use of fossil fuels.

Schaeffer's electrically powered steam machine also makes all the millions of constantly burning pilot lights obsolete

Among the more than 500 applications for steam, the Schaeffer device can effectively heat a modern home with 20 per cent less electricity than is now required.

This machine makes super-heated steam from running cold water instantly and without burning up a great deal of energy.

Sounds impossible doesn't it?

Credibility has been one of the key problems faced by Sonaqua Inc., the small firm that is attempting to develop and license the late inventor's lifetime dream.

Engineers instinctively draw a blank when confronted with the claims of the Sonaqua group. Schaeffer accomplished

something different; something not found in the text books.

Karl Schaeffer was 67 years old when this reporter first interviewed him an photographed his demonstration in 1973. The story was not told sooner because Sonaqua Inc. wanted the product fully developed before publicizing what they had.

The device is still not fully developed, but the story needs telling and our nation needs this new form of energy.

Karl Schaeffer found a way to harness some tremendous natural force which is inherent in molecules of water. There's no other way to state his principle.

"It all started for me when I was a▶
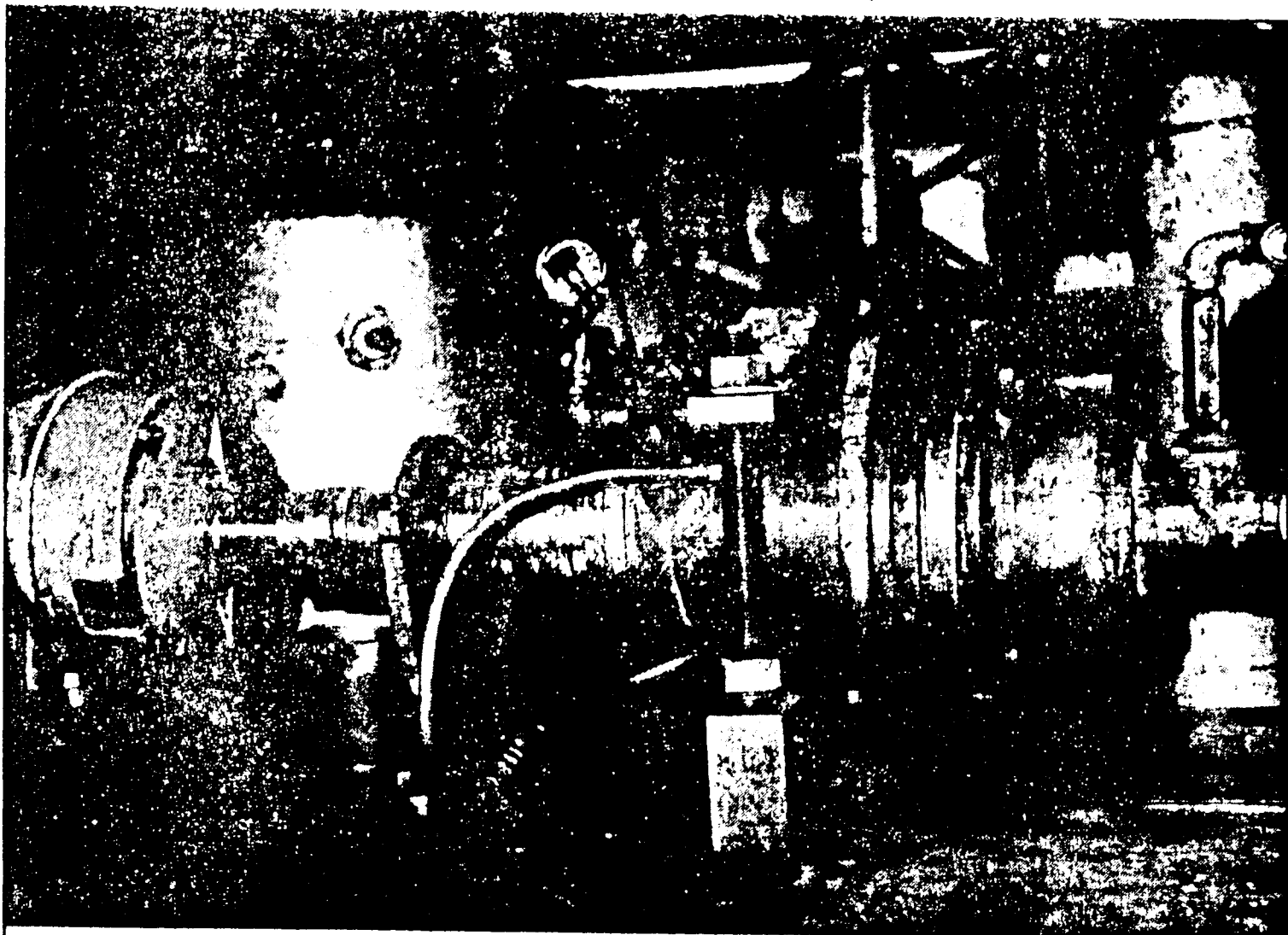
The unlikely looking aggregate of steel above is actually one of the greatest inventions to come along in the era of energy utilization. The device you see is a prototype of Karl Schaeffer's steam machine; it features a standard 20 horsepower electric motor (left) which drives a rotary assembly which shocks water into steam instantly -- no boiler, no flame, no fossil fuels, no pilot light. Low cost steam heat is only one area of benefit.

graduating student of a trade-technical school in Berlin. The year was 1924," Schaeffer said in his thick German accent.

"I was in the washroom and when I turned off the water I heard the pipes knock," he said, referring to what engineers call "water hammer," a phenomenon in pipes that technology tries to eliminate.

"It was a loud knock and my mind suddenly said – there is energy in that water hammer! And from that moment on, I was hooked."

"Of course I wondered if there was a way to harness such an energy, and I began my life-long quest – well, it took me 50 years, but I have harnessed that energy and it can power the world.

"My machine can actually run forever so long as water continues to flow into it. Unlimited steampower! Free energy! Think of it!"

Karl Schaeffer was excused by his aides for "exaggeration." "Exaggeration my foot," Schaeffer bellowed. "I know what I have seen!"

The inventor had an unexplained engineering phenomenon occur four seperate times during the years he was striving to perfect his device. He turned off the electric power to the motor, but the machine kept running until the water in the tank was gone.

Enough power sprang from within his mechanism to continue pouring forth steam from cold water and turn all the mechanical apparatus as well -- with the power off!

Those unexplained incidents led Schaeffer to make claims considered "wild" by others. But even if he was deluded, which does not appear to be the case, his machine is by far the most efficient means of making steam ever devised by man.

Karl Schaeffer did it the hard way -- but after coming to America from his native Germany and devoting all his time and a considerable family fortune to his "mechanical obsession," he finally harnessed that simple shock wave in water phenomenon.

"It appears that this device actually makes use of two principles engineers try to eliminate -- water hammer and cavitation," noted Dr. Tom Hunter, former professor of Mechanical Engineering at Illinois Institute of Technology when he watched a demonstration of the Schaeffer machine.

"The force in the water is always there -- I have learned to use it, to intensify and use it," Schaeffer said emphatically.

One expert in engineering, chemistry and physics while watching the Schaeffer machine spin and spew forth steam said:

"I believe he is releasing energy that is inherent in molecules of water and this puts us on the verge of a totally new concept of energy utilization."

Essentially it is apparent that the vibrational and shock-wave nature of water can be used as a source of additional energy.

The Schaeffer machine is run by an electric motor that spins a metal disc. Cold water runs into the spinning flywheel where specially designed chambers cause an extremely rapid series of

shocks to occur – literally shocking the water into superheated steam.

Schaeffer demonstrated this energy conversion device in his machine shop on Belmont Avenue in Chicago for this reporter a number of times. The device was crude and inefficient next to some later models made by Bob Price of Sonaqua, but it was impressive nonetheless.

"You just watch what happens," the old man said proudly as he stepped up to his floor mounted machinery. "You know how long it takes to boil water on your stove don't you?" he asked.

I nodded that I understood a little about boilers, heaters and making steam.

"Feel this," he ordered and I put my hand on some pipes leading into the device from a water tank. It was cold -- tap water cold.

A 20 horsepower electric motor was mounted beneath the heavy metal rotary impeller. A pipe protruded from
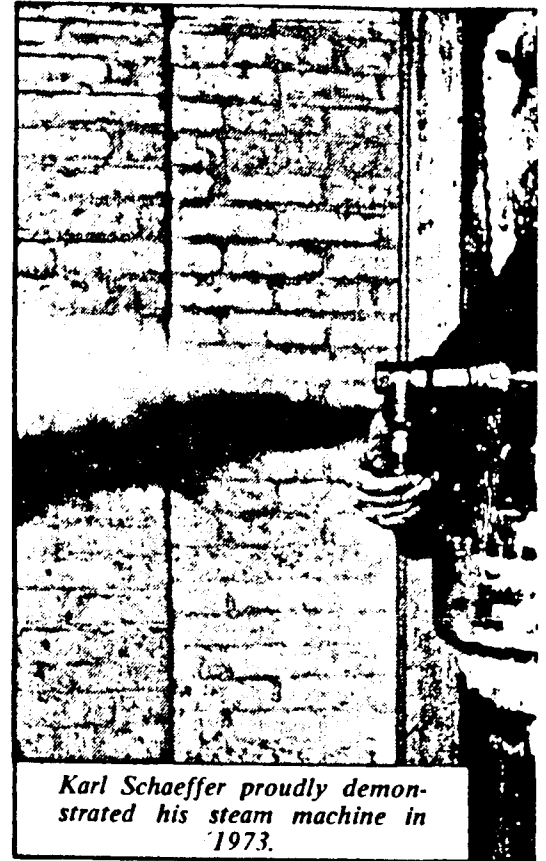
Karl Schaeffer proudly demonstrated his steam machine in 1973.

the opposite side of the disc and bent up and out a window.

Schaeffer pulled a switch and I witnessed an amazing energy conversion – something totally new to the annals of engineering. The motor whirred and Schaeffer tinkered with a valve for about 20 seconds, then before half a minute had elapsed superheated steam spewed forth and cascaded out the window.

The outlet pipe was too hot to touch in a very short time, yet the inlet pipe continued to be as cold as the water running inside it.

Indeed, a 20 horsepower electric mo-

tor is an energy source, but later tests and more sophisticated equipment showed that the power out -- in the form of steam -- was greater than the power in from the electric outlet source -- an engineering impossibility! But a fact nonetheless.

In September of 1973 Sonaqua Inc. took the Schaeffer device to famed Battelle research institute in Columbus, Ohio for efficiency tests.

The test results, submitted to George W. Moffit Jr., board chairman of Sonaqua Inc. on Oct.4, 1973 by L.J. Flanigan of the Nuclear and Flow Systems Section of Battelle, listed the efficiency of the device over eight test runs to be in a range between 97.3 per cent and 99.0 per cent.

An interesting aside to the formal report is that much of the experimentation was said to have been "not definitive because shortcomings in the experimental apparatus introduced large

uncertainties into the results."

However, it was reported by Battelle personnel, that part of that same unexplained phenomenon reported by the inventor must have developed: "We had readings in excess of 100 per cent on several occasions," an engineer told Bob Price, "and that's not possible."

"I was told that one of the readings actually indicated an efficiency of 117 per cent," Price said, trying to subdue a grin at the thought of the confusion such a development must have caused the engineers.

The Sonaqua people, especially Price, are careful to avoid any claims for the

unexplained energy at this time. "We have the greatest efficiency and potentially the lowest cost apparatus for making steam there is," Price said.

Sonaqua did manage to sell a licensee the right to produce home heaters, only to find that after two years the licensee is having the same developmental problems faced by the parent company -- the new departure is up against dogmatic slide-rule skepticism and development money is hard to find.

Aquasonics of Denver has proven that a three bedroom home with a basement can be comfortably heated with two small three horsepower motors.

"They have managed to heat a home with 20 per cent less electricity than that used by a standard emersion unit -- and they have had no trouble keeping the house warm --excessively warm," Price said.

For two winters now a model house in the chilly mountain city has had more than adequate heat from the two small motors and the Schaeffer device.

Sonaqua is applying for grants to study exactly what it is that makes the shocked water heat up. Schaeffer's sons, Kurt and Karl, have worked with Bob Price and have designed some experiments to help discover precisely what takes place within their father's mechanical device.

Whether grants for such studies are forthcoming or not, it seems silly to have the use of the device withheld. There's no doubt that it works. Time enough to figure out *why* after it's in

production and helping to curb America's excessive energy use.

Edison's light bulbs were giving light when electric theory was in its infancy. It's not necessary to know precisely what is going on in Schaeffer's machine -- the machine works consistently and that's what is needed.

Dr. Hunter, who viewed the device in action in this reporter's presence, said that it obviously performed in a wide range of efficiencies and eventually when the device was properly developed and finely tuned, the prospects were excellent for the product.

The professor of mechanical engineering did not care to comment on the "unexplained" part of the story.

Look at it this way. If the machine merely produces steam with a 98 per cent efficiency (which Battelle grants unequivocally) then its the best thing for home use yet developed.

And there's no need for large hot water storage tanks as smaller storage units, heated more efficiently will suffice; no need for pilot lights and natural gas.

In large apartment units there's no need for expensive boiler systems and either gas or coal fuel.

And if, when the skepticism is worn down and serious thought is given the device, the "unexplained phenomenon of the release of energy inherent in the molecules of water" is eventually proved and controlled, the world will have an alternative energy source that is sorely needed.

Improved Acoustic Levitation Apparatus

Concave surfaces enhance and shape
acoustic forces to lift heavier objects.

Marshall Space Flight Center, Alabama

A proposed single-axis acoustic resonance system incorporates concave drivers and reflectors to increase the levitation force up to a factor of 6 as compared to conventional flat-shaped elements. A ring element inserted between the concave surfaces controls the standing-wave pressure pattern, particularly critical in levitating liquids.

In the new arrangement (see figure) a cylindrical aluminum reflector and a driver have spherically-machined concave surfaces facing each other and separated by a distance equal to the smaller radius of curvature of one of the elements. Generally, the reflector surface has the greater radius of curvature for a more stable radiation pressure. The driver is coupled with a magnetic driving device (e.g., magnetostrictive or St. Clair device) to form an ultrasonic transducer.

A single levitation node is formed by the standing-wave field between the driver and the reflector. The field is shaped by a ring element between the driver and the reflector. All of the pressure-wave patterns are focused or shaped within the ring as it is moved between the driver and the reflector. The levitated object generally remains inside this ring.

The apparatus may be modified to a lesser extent by using one concave and one flat opposing surfaces. This would increase the levitating force by about a factor of 2 as compared with the conventional flat elements.

Another alternative involves using concave elliptical surfaces to obtain multiple off-axis levitation nodes. This more complex field may be controlled by similar washer elements, screens, or other passive or secondary reflectors positioned at different points about the axes. This configuration would be favorable in levitating two different liquids or materials that are heated separately and then brought together to determine the heat of the
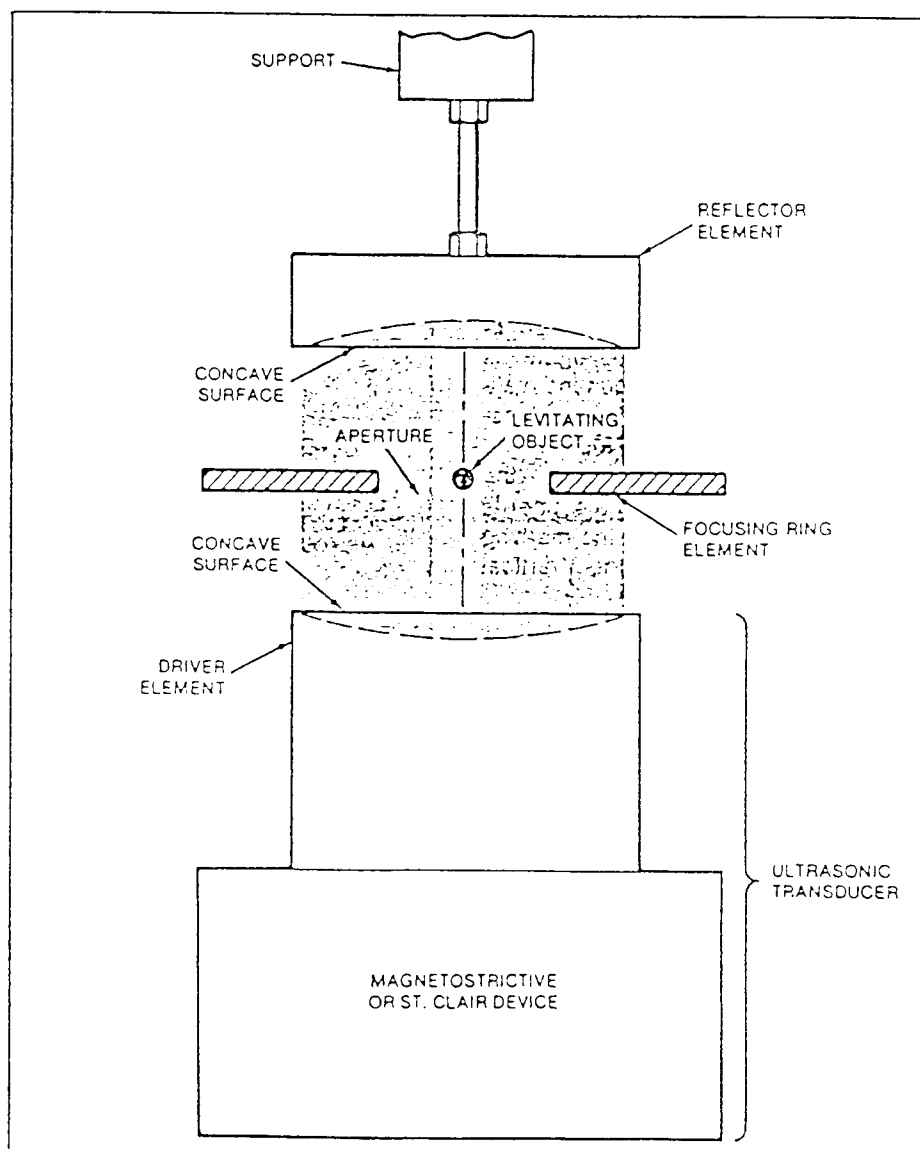
Concave Driver and Reflector enhance and shape the levitation forces in an acoustic resonance system. A single-mode standing-wave pattern is "focused" by a ring element situated between the driver and the reflector. Concave surfaces increase the levitating forces up to a factor of 6 as opposed to conventional flat surfaces, making it possible to suspend heavier objects.

reaction.

ı echnical
Supoort Package

George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama 35812

Improved Acoustic Levitation Apparatus
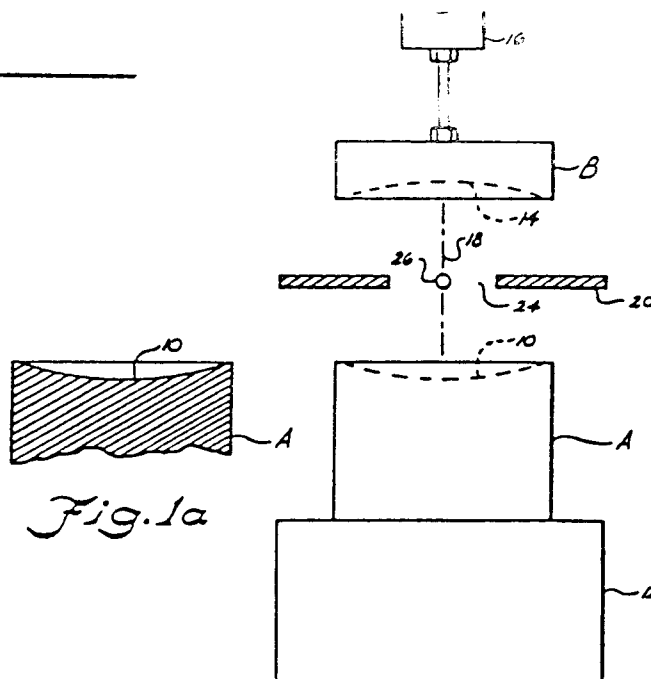
Fig.1a

Fig.1
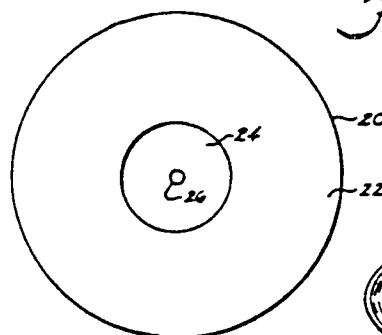
Fig.4

Fig.3
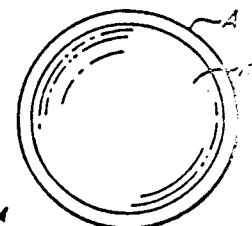
Fig.2

MFS-25050

METHOD AND APPARATUS FOR SHAPING AND ENCHANCING ACOUSTICAL LEVITATION FORCES

ABSTRACT OF THE DISCLOSURE

A method and apparatus for enhancing and shaping acoustical levitation forces in a single-axis acoustic resonance system wherein specially shaped drivers and reflectors are utilized to enhance the levitation force and better contain fluid substances by means of field shaping.

Origin of the Invention

Background of the Invention

This invention relates to an apparatus and method for suspending and positioning objects by the use of acoustical energy. In many instances, the study of materials and material processes and the determination of their properties can be more readily accomplished when the specimens under study are maintained out of contact with the walls of containers and solid supports. A levitated specimen of a material may be advantageously heated in a levitation furnace or by a spot heating device such as a laser.

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A TIBETIAN LEVITATION

TECHNIQUE

TRANSLATED BY WALTER P. BAUMGARTNER

Levitation was not possible for man as long as he had to deal with solids and physical space. With water and air, he had some success. It is only lately that physics has reached another step, where it is able to concentrate energy better through electric fields or through condensation of sound.

East Indian Yogis are supposed to have the capacity to go into a state of levitation through concentration and meditation. The lifting of the heaviest human with the fingertips of four persons belongs in this category.

Priests in the far East are able to lift heavy rocks up high mountains by levitation through a "bunching together" of different sounds or tones.

Sounds experience a concentration by resonance. Through knowledge of the different frequencies in the tone range, the physicist can explain the resonating and concentrating sound tone-mantle used to create levitation. Engineer Olaf Alexandersson, Sweden, wrote on that point in Implosion No. 13 among other things:

"The following report is based on an observation which was made 20 years ago in Tibet. This report is from a friend who was an engineer and flight director by the name of Henry Kjellson. He later recorded this report in his book, A Lost Technique." This report follows:

"A Swedish doctor, Dr. Jarl, a friend of Kjellson, was studying at Oxford, and at the time he became friendly with a Tibetian student. A few years later, in the year 1939, Dr. Jarl traveled to Egypt in the service of an English scientific association. There he was looked up by a man sent from his Tibetian friend in Tibet and he was asked to come to Tibet to look after the high lama in his professional capacity as a medical doctor. After Dr. Jarl had made arrangements to leave the service of the English scientific association, he followed the man to go on a long trip with plane and caravan up to the monestry in Tibet where the old lama and his friend resided.

Dr. Jarl stayed there for quite awhile and thanks to his

Dr. Jarl had heard of this Tibetian stone-throwing before. Knowers of Tibet like Linauer, Spalding, and Huc have also heard of this but have never seen it for themselves. Therefore Dr. Jarl was the first foreigner who had the opportunity to witness this strange spectacle. Since he first believed that he was the victim of a mass hypnosis, he subsequently made two films of this spectacle. However, after the films were developed, he saw exactly what he had experienced. The English scientific association for which he worked took the films away and pronounced them secret and said they would be released in 1990. This is just unbelievable."
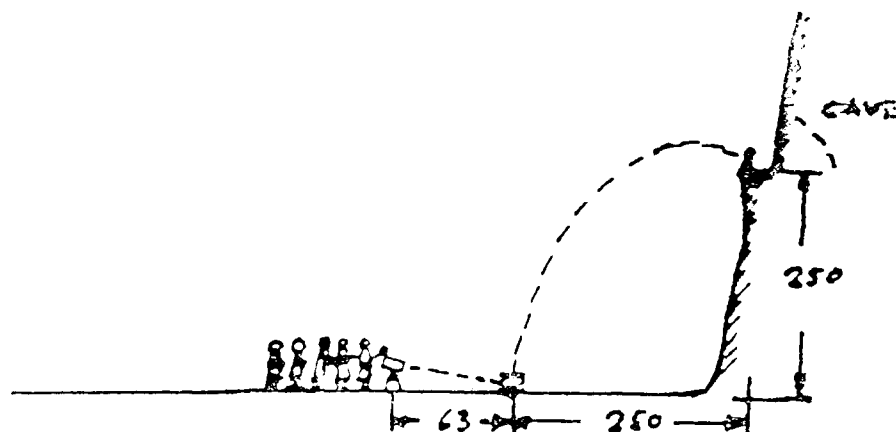
Fig. 1. Sideways View of Stone, Instruments and Levitation Path

L=large drum
M=medium drum
S=small drum
T=trumpet

cliff face
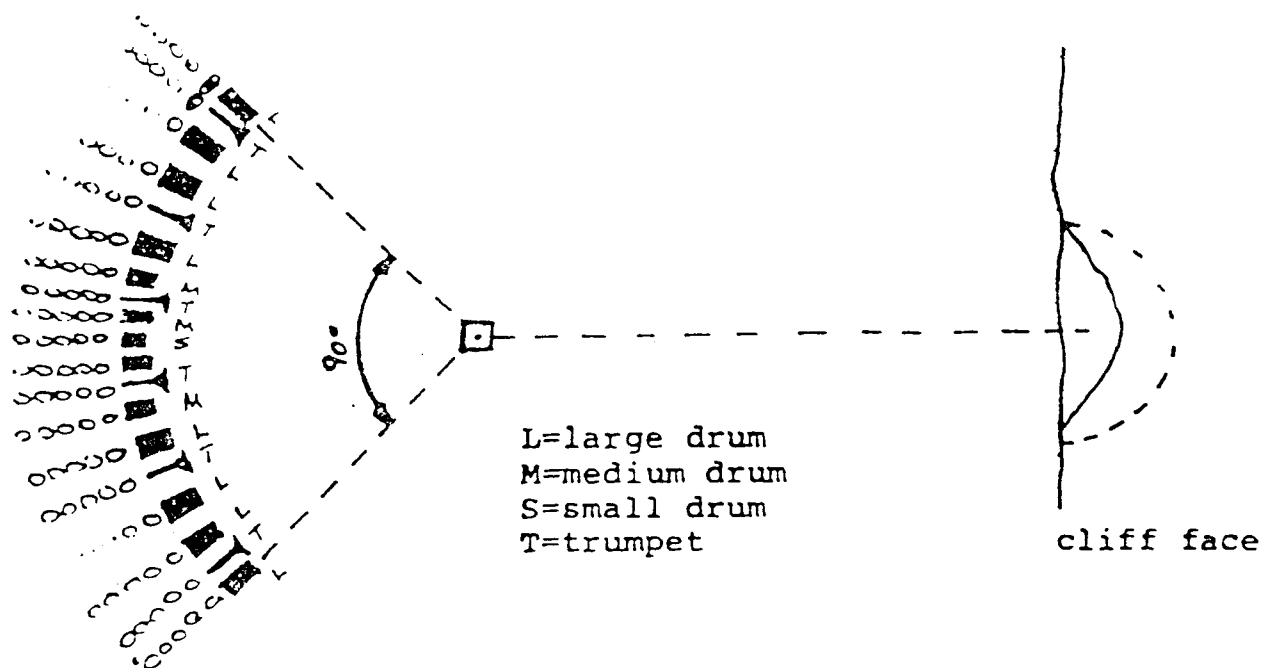
Fig. 2. Top-down View of Placement of Stone and Musical Instruments

THE SECRETS OF LEVITATION

A New Zealand scientist recently gave me an intriguing extract from an article published in a German magazine, relating to a demonstration of levitation in Tibet. After obtaining a translation by a German journalist, in English, I was amazed at the information contained in the story, and was surprised that the article had slipped through the suppression net which tends to keep such knowledge from leaking out to the public. All the similar types of stories that I had read up until now were generally devoid of specific information necessary to prove the veracity of the account. In this case a full set of geometric measurements were taken, and I discovered, to my great delight, that when they were converted into their equivalent geodetic measures, relating to grid harmonics the values gave a direct association with those in the unified harmonic equations published in my earlier works.

The following extracts are translations taken from the German article: "We know from the priests of the far east that they were able to lift heavy boulders up high mountains with the help of groups of various sounds... the knowledge of the various vibrations in the audio range demonstrates to a scientist of physics that a vibrating and condensed sound field can nullify the power of gravitation. Swedish engineer Olaf Alexanderson wrote about this phenomenon in the publication, Implosion No. 13.

The following report is based on observations which were made only 20 years ago in Tibet. I have this report from civil engineer and flight manager, Henry Kjelson, a friend of mine. He later on included this report in his book. The Lost Techniques. This is his report:

A Swedish doctor, Dr Jarl, a friend of Kjelsons, studied at Oxford. During those times he became friends with a young Tibetan student. A couple of years later, it was 1939, Dr Jarl made a journey to Egypt for the English Scientific Society. There he was seen by a messenger of his Tibetan friend, and urgently requested to come to Tibet to treat a high Lama.

After Dr Jarl got the leave he followed the messenger and arrived after a long journey by plane and Yak caravans, at the monastery, where the old Lama and his friend who was now holding a high position were now living.

Dr Jarl stayed there for some time, and because of his friendship with the Tibetans he learned a lot of things that other foreigners had no chance to hear about, or observe.

One day his friend took him to a place in the neighbourhood of the monastery and showed him a sloping meadow which was surrounded in the north west by high cliffs. In one of the rock walls, at a height of about 250 metres was a big hole which looked like the entrance to a cave. In front of this hole there was a platform on which the monks were building a rock wall. The only access to this platform was from the top of the cliff and the monks lowered themselves down with the help of ropes.

In the middle of the meadow, about 250 metres from the cliff, was a polished slab of rock with a bowl like cavity in the centre. The bowl had a diameter of one metre and a depth of 15 centimetres. A block of stone was manoeuvred into this cavity by Yak oxen. The block was one metre wide and one and one-half metres long. Then 19 musical instruments were set in an arc of 90 degrees at a distance of 63 metres from the stone slab. The radius of 63 metres was measured out accurately. The musical instruments consisted of 13 drums and six trumpets. (Ragdons).

Eight drums had a cross-section of one metre, and a length of one and one-half metres. Four drums were medium size with a cross-section of 0.7 metre and a length of one metre. The only small drum had a cross-section of 0.2 metres and a length of 0.3 metres. All the trumpets were the same size. They had a length of 3.12 metres and an opening of 0.3 metres. The big drums and all the trumpets were fixed on mounts which could be adjusted with staffs in the direction of the slab of stone. The big drums were made of 3mm thick sheet iron, and had a weight of 150 kg. They were built in five sections. All the drums were open at one end, while the other end had a bottom of metal, on which the monks beat with big leather clubs. Behind each instrument was a row of monks. The situation is demonstrated in the following diagram:

DIAGRAM 21
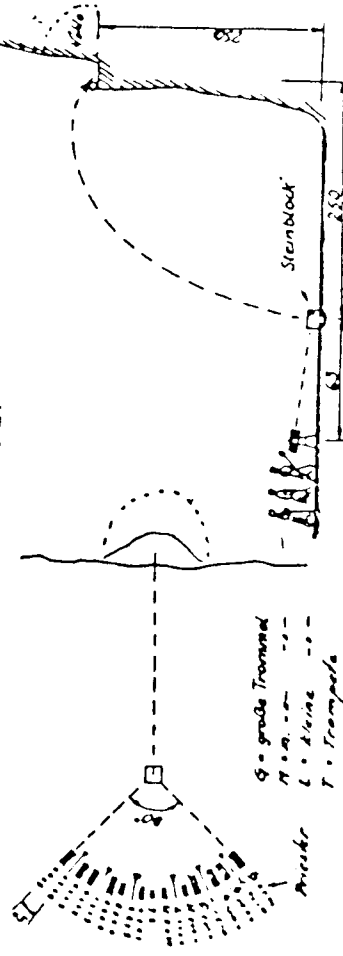
When the stone was in position the monk behind the small drum gave the signal to start the concert. The small drum had a very sharp sound, and could be heard even with the other instruments making a terrible din. All the monks were singing and chanting a prayer, slowly increasing the tempo of this unbelievable noise. During the first four minutes nothing happened, then as the speed of the drumming, and the noise, increased, the big stone block started to rock and sway, and suddenly it took off into the air with an increasing speed in the direction of the platform in front of the cave hole 250 metres high. After three minutes of ascent it landed on the platform.

Continuously they brought new blocks to the meadow, and the monks using this method, transported 5 to 6 blocks per hour on a parabolic flight track approximately 500 metres long and 250 metres high. From time to time a stone split, and the monks moved the split stones away. Quite an unbelievable task.

Dr Jarl knew about the hurling of the stones. Tibetan experts like Linaver, Spalding and Huc had spoken about it, but they had never seen it. So Dr Jarl was the first foreigner who had the opportunity to see this remarkable spectacle. Because he had the opinion in the beginning that he was the victim

of mass-psychosis he made two films of the incident. The films showed exactly the same things that he had witnessed.

The English Society for which Dr Jarl was working confiscated the two films and declared them classified. They will not be released until 1990. This action is rather hard to explain, or understand. : End of trans.'

The fact that the films were immediately classified is not very hard to understand once the given measurements are transposed into their geometric equivalents. It then becomes evident that the monks in Tibet are fully conversant with the laws governing the structure of matter, which the scientists in the modern day western world are now frantically exploring. It appears, from the calculations, that the prayers being chanted by the monks did not have any direct bearing on the fact that the stones were levitated from the ground. The reaction was not initiated by the religious fervour of the group, but by the superior scientific knowledge held by the high priests. The secret is in the geometric placement of the musical instruments in relation to the stones to be levitated, and the harmonic tuning of the drums and trumpets. The combined loud chanting of the priests, using their voices at a certain pitch and rhythm most probably adds to the combined effect, but the subject matter of the chant, I believe, would be of no consequence.

The sound waves being generated by the combination were directed in such a way that an anti-gravitational effect was created at the centre of focus (position of the stones) and around the periphery, or the arc, of a third of a circle through which the stones moved.

If we analyse the diagram published with the original article, then compare it with the modified diagram, we become aware of the following coordinates, and the implications, when compared with my previously published works.

The distance between the stone block and the central pivot of the drum supports is shown as 63 metres. The large drums were said to be one and one half metres long, so the distance from the block to the rear face of each drum could be close to 63.75 metres considering that the pivot point would be near the centre of balance. My theoretical analysis, by calculator, indicates that the exact distance would be 63.7079 metres for the optimum harmonic reaction.

By mathematical conversion we find that this value is equal to 206.2648062 geodetic feet, which is harmonically equal to the length of the earth's radius in seconds of arc (relative to the earth's surface) 206264.8062. This also leads us to the following associations:

(206.2648062 x 2)
= 412.5296124

This number squared:
= 170180.68 which is the theoretical harmonic of mass at the earth's surface.

The four rows of monks standing behind the instruments in a quarter circle added to the production of sound by their loud chanting and must be taken in to account in regards to the geometric pattern. If we assume that they were standing approximately two feet apart, we can add a calculated value of 8.08865 geodetic feet to the radius of the complete group. This gives a maximum radius of:
214.3534583 geodetic feet.

The circumference of a complete circle with this radius would be:
1346.822499 geodetic feet.
Which is a half harmonic of:
2693.645 (unified field)

The distance from the stone block to a calculated point within the cliff face and the height of the ledge on the cliff face from ground level is given as 250 metres. If we can now imagine that the raised stone blocks pass through a quarter arc of a circle during their flight from ground level to the hole in the cliff face, then the pivot point of the radius would be coincident with this position. See diagram.

The theoretical radius was found to be:
249.876262 metres which very closely approximates the estimate.
This converts to:
809.016999 geodetic feet.
The diameter of the full circle would therefore be:
1618.034 geodetic feet.

A circle with this diameter has a circumference of 5083.203728 units, which can be divided into three even lengths of 1694.4. It therefore appears that the levitated blocks, once resonated to a certain frequency, would tend to carry out a flight path that is coincident to one third of a circle. The spacial distance being equivalent to the mass harmonic at the centre of a light field, 1694443.

The instruments used by the group, in theory, would also have been tuned to produce harmonic wave forms associated with the unified fields. The given measurements are in rounded off parts of a metre but in practice some slight variations from these measurements would be expected in order to create the appropriate resonating cavities within the instruments. The geometric arrangement, and the number of instruments in the group would also be a most important factor.

If the given measurement for each type of drum is modified fractionally and converted to its geometric equivalent an interesting value for the cubic capacity is evident.
The large drums:
1.517201563 metres long, 1.000721361 metres wide
= 58.94627524 geodetic inches long, 38.88 geodetic inches wide
= 69984 cubic geodetic inches capacity
= 40.5 cubic geodetic feet capacity.
Therefore the cubic capacity for eight drums:
= 324 cubic geodetic feet.
This harmonic value is built into the world grid and is equal to half the harmonic 648.
The medium sized drums:
1.000721361 metres long, 0.695189635 metres wide
= 38.88 geodetic inches long, 27.00948944 geodetic inches wide
= 22276.59899 cubic geodetic inches capacity
= 12.89155034 cubic geodetic feet capacity.
Therefore the cubic capacity for four drums:
= 51.56620136 cubic geodetic feet.

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If we multiply this value by 8 to allow for the interference pattern at the focal point caused by the eight larger drums we have:

412.5296108

This number squared:

= 17018068 the mass harmonic at the earth's surface.

The small drum:

0.303440311 metres long, 0.2001444272 metres wide

= 11.789255501 geodetic inches long, 3.888 geodetic inches wide

= 559.8719984 cubic geodetic inches capacity.

= 0.324 cubic geodetic feet capacity.

The harmonic produced from the small drum is therefore the same as that produced from the large drums but at a much higher pitch.

The trumpets:

The length of each trumpet, slightly modified, would be:

3.112550314 metres

= 120.928723 geometric inches.

The length of six trumpets combined would be:

725.572338 geodetic inches.

The square root of this number:

26.93645 (the harmonic 2693645, unified equation).

The width of the bell mouth of each trumpet:

0.303440311 metres

= 11.789255 geodetic inches, which is equal to the length of the small drum.

The blocks of stone which were levitated were said to have the same basic dimensions as the large drums, although the drums were cylindrical in shape and the stones square cut. If we use the same modified measurements, then:

The blocks of stone:

= 1.517201563 metres long, 1.000721361 metres wide

= 58.94627524 geodetic inches long, 38.88 geodetic inches wide

= 89106.39633 cubic geodetic inches capacity

= 51.56620157 cubic geodetic feet capacity

If we multiply this value by 8 and square it as we did with the medium sized drums then the resultant harmonic:

= 170180.68 again the mass harmonic at the earth's surface.

Finally in our theoretical exercise we come to the polished slab of rock with the bowl shaped cavity at the centre, upon which the cut stones were placed in order to be levitated. Obviously the polished cavity had a purpose, and helped to create a frequency vortex within which the cut stones were raised. A full analysis cannot be given at this time as the radius of the cavity has not been calculated, but the given measurements are interesting in themselves. The cavity width of one metre would be similar, when modified slightly, to the stone blocks:

1.000721361 metres

= 38.88 geodetic inches

=3.24 geodetic feet (half the harmonic of 648)

The depth of the cavity, given as 15 centimetres would have a revised calculated value of:

14.97414932 centimetres

= 5.895334377 inches

= 5.817764187 geodetic inches

= 0.484813682 geodetic feet.

As the dish-shape was focussed upwards towards the stone block to be levitated it would be expected that some type of reaction would take place which had an effect on the mass. The geometric shape of the cavity does seem to be engineered in such a way that the projected frequency vortex causes a reciprocal reaction to the mass harmonic of each block.

The reciprocal of:

0.484813682

= 2.062648055

Twice this value:

= 4.12529611

The square of this value:

= 17.018068 (the harmonic of mass at the earth's surface. 17018068)

I believe that there is not much doubt that the Tibetans had possession of the secrets relating to the geometric structure of matter, and the methods of manipulating the harmonic values, but it we can grasp the mathematical theory behind the incident, and extend the application, then an even more fascinating idea presents itself.

In my last book I mentioned the flying machines described in ancient records, that flew through the air with a melodious sound, and theorised that the sonic apparatus was tuned to the harmonic unified equations.

Now the Tibetans have given us a direct indication of how to construct a sonically propelled anti-gravitational flying machine. All that is necessary is to complete the circle of sonic generators, indicated by the drums, trumpets, etc., and we have a disc which creates an anti-gravitational lifting force at the centre. (see diagram 23).

To create this diagram I made four photo-copies of the original illustration showing the arrangement of drums, trumpets etc. and then cut out the 90 degree segments and fitted them together into a circular pattern. This was then photo-copied a second time in the relationship with a disc-shaped vehicle. When the circular pattern was formed it became evident that the Tibetans had placed the drums and trumpets on the arc of a quarter circle, but the placement of the Priests behind the drums tended to form a spiral. This conforms with the concept of the formation of matter due to the spiralling, vortexual, wave motions in space, discussed in my earlier works. Similar wave motions would have to be created in order to manipulate matter.

The inner diameter of the sonic generators in the theoretical vehicle would be 412.5296 geodetic feet, with the previously described harmonic associations. The outer diameter, estimated from the placement of the Tibetan priests, would be 428.7069166 geodetic feet. If we square the inner diameter we have the harmonic of mass 17018068 relative to the earth's surface, and the outer diameter would give a circumference tuned to the unified equation. The lift vectors through the centre would resonate at

DIAGRAM 23

Diagram showing how the geometric pattern of sonic generators created by the Tibetan Monks can be combined in a circular, or disc, shape. the resultant forces of the harmonic fields set up would combine into a doughnut shaped anti-gravitational field which would levitate the disc, or vehicle.

Radius of field
809.016999 geo/ft

428.7069166 Geo/ft.

412.5296 Geo/ft.

Plan view

Radius of field
809.016999 geo/ft.

Disc shaped vehicle

Side elevation

Field creates an anti-gravitational effect.

412.5296 squared = 170180.68 = mass harmonic
428.7069166 diameter = circumference of 1346.822499
= half harmonic of 2693.645 (unified equation)

harmonic frequencies in opposition to the mass value at the centre of a unified, or light, field = 1694443.

From this it would appear that a vehicle could be constructed that would resonate at frequencies in sympathy with the unified fields demonstrated throughout this work.

It is my opinion that our own scientific establishments are far ahead in this type of research, and that many experimental vehicles have already been constructed. High frequency generators have probably taken the place of the low frequency sonic methods, and electronic systems produced which would allow complete control of movement.

With this type of research going on, I would say that the days of the conventional aeroplane are numbered.

DIAGRAM 22

Showing relationship of Priests, drums and stone blocks, to the hole in the cliff face.

Not to scale

Radius

Distance
A = 8.08865 geo/ft.
B = 206.2648062 geo/ft.
C = 809.016999 geo/ft.
D = 809.016999 geo/ft.

Mistake in the Making
song by Kate Bush

We were working secretly for the military
our experiment in sound
was nearly ready to begin
we only know in theory what we are doing
music made for pleasure, music made to thrill
it was music we were making here until
they told us all they wanted
was a sound that could kill someone
from a distance, so we go ahead
and the meters are over in the red
there's a mistake in the making
from the painful cries of mothers
to the terrifying screams
we were cordoned, tied and ported into our machine...

French Scientists Experiment With Sonic Death-Ray Machine

By FRANK DORSEY
The London Sunday Times

LONDON — A team of French scientists in Marseilles is working on a death-ray machine designed to provide an entirely novel method of human destruction.

The project began when the electro-acoustical laboratory of the French National Center for Scientific Research moved into a new building three years ago. Staff complained of headaches and nausea. Investigations begun. Electromagnetic waves were suspected and eliminated. So were ultrasound waves, the laboratory's major interest for 18 years.

At this point, one of the technicians got out an antique apparatus for detecting infrasound — that is, air vibrations which oscillate at less than 10 vibrations a second, or 10 hertz. (The human ear registers, as sound, vibrations from 16 per second, or 16 hertz, to 20,000 hertz.)

It quickly identified the source of the unease: The giant ventilator of the factory next door. After changing the ventilator's frequency, the five-man team, headed by Prof. Vladimir Gavreau, decided to find out more about the properties of infrasound.

Sound is a succession of waves in which the air is alternately compressed and decompressed. Fast vibrations either go right through solid objects or bounce off them, usually doing relatively little harm even when very powerful.

But slow air vibration, below the hearing level, can create a sort of pendulum action, a reverberation in solid objects that quickly builds up to intolerable intensity. Anyone who has stood close to the low-pitched siren of an ocean-liner has an inkling of what infrasound can do.

To study this phenomenon, the team built a giant whistle, hooked to a compressed-air hose. Then they turned on the air.

"That first test nearly cost us all our lives," Prof. Gavreau says. "Luckily, we were able to turn it off fast. All of us were sick for hours. Everything in us was vibrating — stomach, heart, lungs. All the people in the other laboratories were sick, too. They were very angry with us."

From then on, the team worked at lowering the frequency, but carefully kept the power input down. It was discovered that the wave-length most dangerous to life is 7 vibrations per second.

At 7 hertz, turned on very softly, one has a vague impression of sound and a feeling of general discomfort. At 3.5, nothing can be heard directly, but there is a curious incidental effect. Nearby sounds, such as air hissing into the pipe, take on a pulsing quality — at three and a half pulsations a second sounds in the neighborhood seem to ululate rhythmically.

The team has suffered from its experiments. Some of the invisible injuries appear to be persistent.

"It not only affects the ears," Gavreau says, "but it works directly on the internal organs. There is a rubbing between the various organs because of a sort of resonance. It provokes an irritation so intense that for hours afterwards any low-pitched sound seems to echo through one's body."

In developing a military weapon, the scientists intend to revert to the policeman's whistle form, perhaps as big as 18 feet across, mount it on a truck and blow it with a fan turned by a small airplane engine. It could kill a man five miles away.
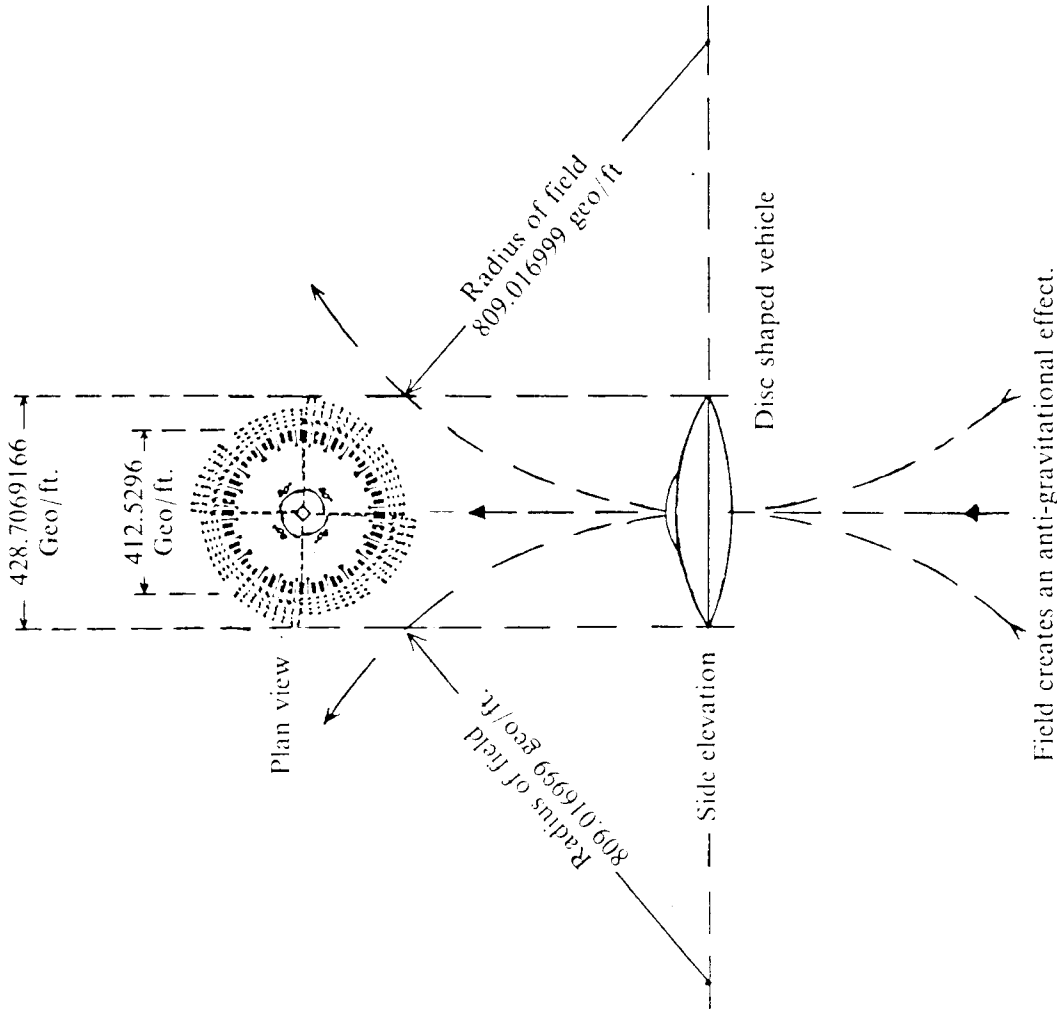
There is one snag. At present, the machine is as dangerous to its operators as to the enemy. The team is working on a way to focus it. Various systems of baffles have been tried, but the most promising method appears to be propagation of a different and complementary sound wave length backwards from the machine. This changes the frequency of air wave lengths moving in that direction, thus protecting anyone to the rear.

Sounds That Kill

DEADLY sound waves, of such high frequency that they are inaudible, recently have been produced by Prof. R. W. Wood, of Johns Hopkins University, and A. L. Loomis, in the latter's laboratory at Tuxedo Park, N. Y., using a quartz sheet vibrated 500,000 times a second by electricity. The experimenters found that when these waves were generated in a tank of water containing a number of small fish, the fish were mysteriously killed, their muscles reduced to a pulp.

In further studies reported to the National Academy of Sciences, the scientists discovered that blood corpuscles in salt water are broken down by the strange vibrations, and the whole fluid is tinged a clear red—unless a trace of gelatin is added. Artificial ice, compressed and placed in contact with the waves, is shattered into small crystals.

Oil, paraffin, and mercury, considered impossible to mix with water, combine with it under the silent sound waves to form semi-opaque mixtures. Thus, when a paraffin candle was suspended in the water, the wax melted from the surface to form a "paraffin milk" that resembled

SOUNDS EXCITING

Sonic crusher tests set

April 12/85

Sound waves extracting oil from tar sands? Magnesium from a mixture of magnesium and limestone? Gold from gold-bearing gravel?

A Vancouver-based company thinks it's possible and is spending about $1 million to buy a prototype sonic crusher from the U.S. to prove it.

RFOil Industries Ltd. president Ted Duncan said the sonic crusher will be tested and, if successful, will be built in Canada for "less than $100,000 each.

"We're very excited by the prospect," Duncan said in an interview Wednesday. "The principle is the same as getting rid of kidney stones by ultra sound."

Duncan said the sonic crusher will generate a wind of mach 1.6, or about 1,200 miles per hour, over a very short distance. "It causes the rock to explode and reduces limestone to talcum power size," said Smith.

The prototype crusher, which was purchased partly through a scientific research tax credit, can also crush four tonnes of coal a day into powder, which could then be blown into furnaces. "We are also going to experiment turning wood into wood fibre," said Duncan.

RFOil was established a couple of years ago to produce a microwave tool to be used in the oil sands.
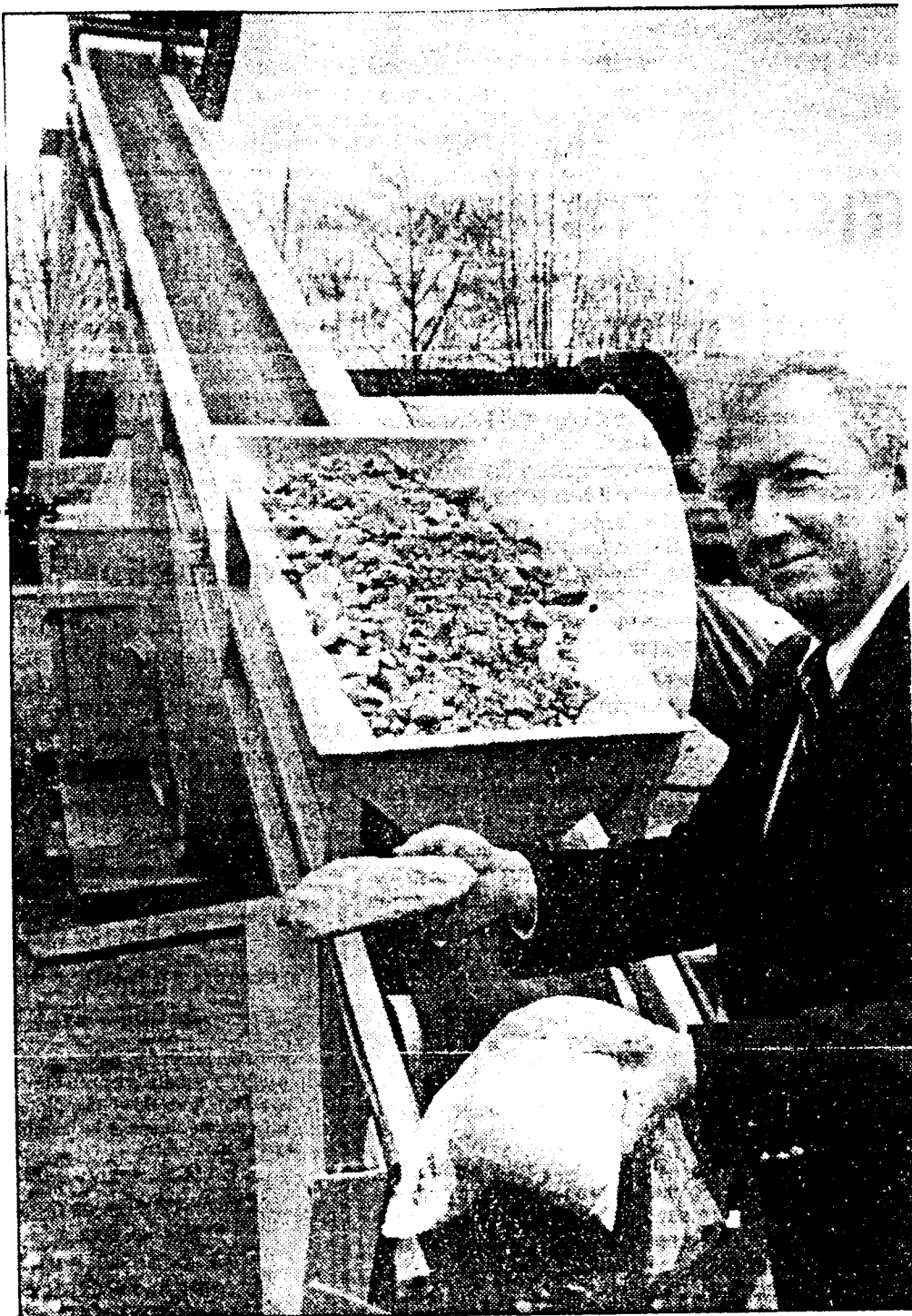
TED DUNCAN WITH PROTOTYPE . . . 'very excited by the prospect'

—Ralph Bower photo

John Tyndall

The Science of Sound

§ 3. *Musical Sounds produced by Puffs*

Prof. Robison was the first to produce a musical sound by a quick succession of *puffs* of air. His device was the first form of an instrument which will soon be introduced to you under the name of the *siren*. Robison describes his experiment in the following words: "A stop-cock was so constructed that it opened and shut the passage of a pipe 720 times in a second. The apparatus was fitted to the pipe of a conduit leading from the bellows to the wind-chest of an organ. The air was simply allowed to pass gently along this pipe by the opening of the cock. When this was repeated 720 times in a second, **the sound**
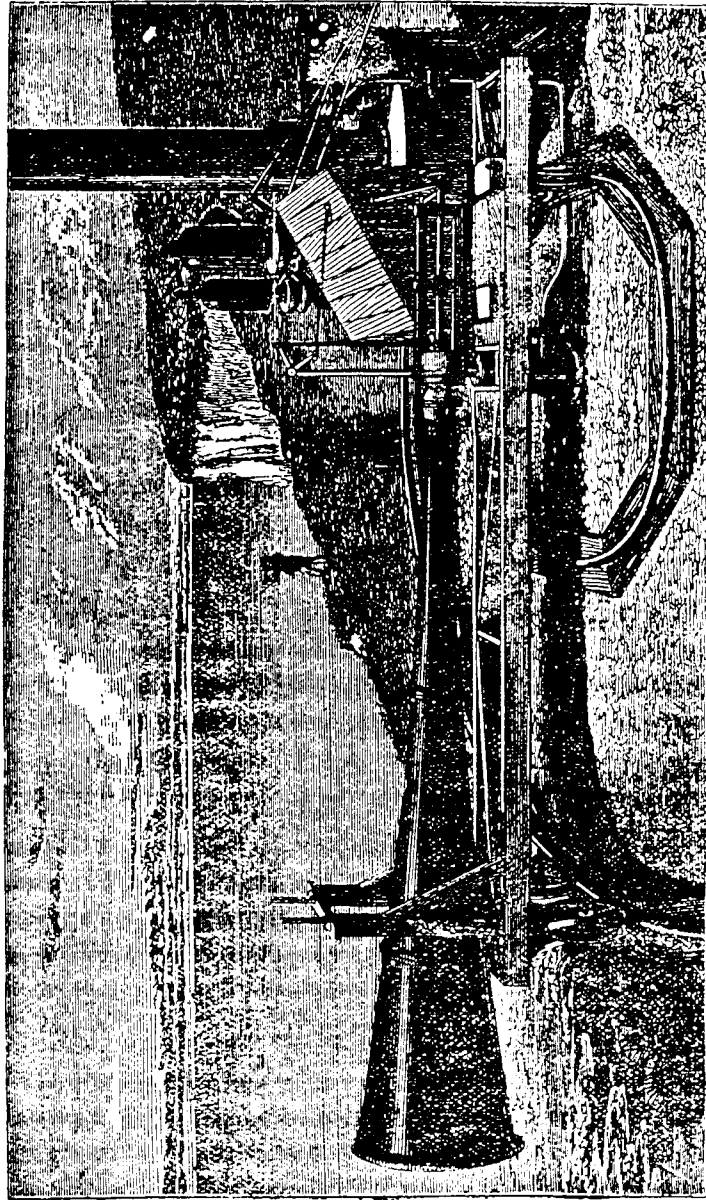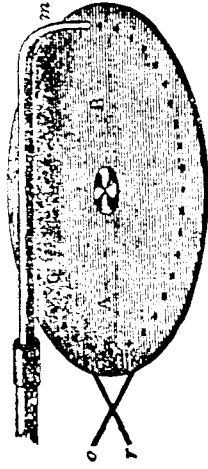
Fig. 18.

g in alt was most smoothly uttered, equal in sweetness to a clear female voice. When the frequency was reduced to 360, the sound was that of a clear but rather a harsh man's voice. The cock was now altered in such a manner that it never shut the hole entirely, but left about one-third of it open. When this was repeated 720 times in a second, the sound was uncommonly smooth and sweet. When reduced to 360, the sound was more mellow than any man's voice of the same pitch."

But the difficulty of obtaining the necessary speed renders another form of the experiment preferable. A disk of Bristol board, B, Fig. 18, twelve inches in diameter, is perforated at equal intervals along a circle near its **circumference. The disk, being strengthened by a backing of tin, can be attached to a whirling table, and caused to rotate rapidly.** The individual holes then disappear, blending themselves into a continuous shaded circle. Immediately over this circle is placed a bent

Fog-Siren

FIG. 19.

tube, m, connected with a pair of acoustic bellows. The disk is now motionless, the lower end of the tube being immediately over one of the perforations of the disk. If, therefore, the bellows be worked, the wind will pass from m through the hole underneath. But if the disk be turned a little, an unperforated portion of the disk comes under the tube, the current of air being then intercepted. As the disk is slowly turned, successive perforations are brought under the tube, and whenever this occurs a puff of air gets through. On rendering the rotation rapid, the puffs succeed each other in very quick succession, producing pulses in the air which blend to a continuous musical note, audible to you all. Mark how the note varies. When the whirling table is turned rapidly the sound is shrill; when its motion is slackened the pitch immediately falls. If instead of a single glass tube there were two of them, as far apart as two of our orifices, so that whenever the one tube stood over an orifice, the other should stand over another, it is plain that if both tubes were blown through, we should, on turning the disk, get a puff through two holes at the same time. The intensity of the sound would be thereby augmented, but the pitch would remain unchanged. The two puffs issuing at the same instant would act in concert, and produce a greater effect than that obtained by one upon the ear. And if instead of two tubes we had ten of them, or better still, if we had a tube for every orifice in the disk, the puffs from the entire series would all issue, and would be all cut off at the same time. These puffs would produce a note of far greater intensity than that obtained by the alternate escape and interruption of the air from a single tube. In the arrangement now before you, Fig. 19, there are nine tubes through which the air is urged—through nine apertures, therefore, puffs escape at once. On turning the whirling table, and alternately increasing and relaxing its speed, the sound rises and falls like the loud wail of a changing wind.
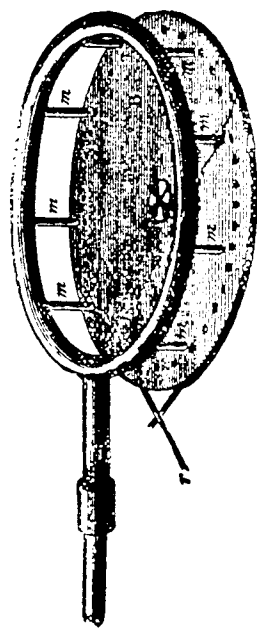
§7. The Siren: Analysis of the Instrument

By the rotation of a perforated pasteboard disk, it has been proved to you that a musical sound is produced by a quick succession of puffs. Had we any means of registering the number of revolutions accomplished by that disk in a minute, we should have in it a means of determining the number of puffs per minute due to a note of any determinate pitch. The disk, however, is but a cheap substitute for a far more perfect apparatus, which requires no whirling table, and which registers its own rotations with the most perfect accuracy.

I will take the instrument asunder, so that you may see its various parts. A brass tube, t, Fig. 26, leads into a round box, c, closed at the top by a brass plate a b. This plate is perforated with four series of holes, placed along four concentric circles. The innermost series contains 8, the next 10, the next 12, and the outermost 16 orifices. When we blow into the tube t, the air escapes through the orifices, and the problem now before us is to convert these continuous currents into discontinuous puffs. This is accomplished by means of a brass disk d e, also perforated with 8, 10, 12, and 16 holes, at the same distances from the centre and with the same intervals between them as those in the top of the box c. Through the centre of the disk passes a steel axis, the two ends of which are smoothly bevelled off to points at p and p'.

fits on to the upper end of the axis $p\ p'$. In this figure the disk $d\ e$ is shown covering the top of the cylinder c. You may neglect for the present the wheel-work of the figure. Turning the disk $d\ e$ slowly round, its perforations may be caused to coincide or not coincide with those of the cylinder underneath. As the disk turns, its orifices come alternately over the perforations of the cylinder and over the spaces between the perforations. Hence it is plain that if air were urged into c, and if the disk could be caused to rotate at the same time, we should accomplish our object, and carve into puffs the streams of air. In this beautiful instrument the disk is caused to rotate by the very air currents which it renders intermittent. This is done by the simple device of causing the perforations to pass *obliquely* through the top of the cylinder c, and also obliquely, but oppositely inclined, through the rotating disk $d\ e$. The air is thus caused to issue from c, not vertically, but in side currents, which impinge against the disk and drive it round. In this way, by its passage through the siren, the air is molded into sonorous waves.

Another moment will make you acquainted with the recording portion of the instrument. At the upper part of the steel axis $p\ p'$, Fig. 27, is a screw s, working into a pair of toothed wheels (seen when the back of the instrument is turned toward you). As the disk and its axis turn, these wheels rotate. In front you simply see two graduated dials,

Fig. 28, each furnished with an index like the hand of a clock. These indexes record the number of revolutions executed by the disk in any given time. By pushing the button a or b the wheel-work is thrown into or out of action, thus starting or sus-

FIG. 28.

My object now is to cause this perforated disk to rotate

FIG. 26.

FIG. 27.

over the perforated top $a\ b$ of the box c. You will understand how this is done by observing how the instrument is put together.

In the centre of $a\ b$, Fig. 26, is a depression x sunk in steel, smoothly polished and intended to receive the end p' of the axis. I place the end p' in this depression, and, holding the axis upright, bring down upon its upper end p a steel cap, finely polished within, which holds the axis at the top, the pressure both at top and bottom being so gentle, and the polish of the touching surfaces so perfect, that the disk can rotate with an exceedingly small amount of friction. At c, Fig. 27, is the cap which

pending, in a moment, the process of recording. Finally, by the pins m, n, n, o, p, Fig. 27, any series of orifices in the top of the cylinder c can be opened or closed at pleasure. By pressing m, one series is opened; by pressing n, another. By pressing two keys, two series of orifices are opened; by pressing three keys, three series; and by pressing all the keys, puffs are caused to issue from the four series simultaneously. The perfect instrument is now before you, and your knowledge of it is complete.

This instrument received the name of siren from its inventor, Cagniard de la Tour. The one now before you is the siren as greatly improved by Dove. The pasteboard siren, whose performance you have already heard, was devised by Seebeck, who gave the instrument various interesting forms, and executed with it many important experiments. Let us now make the siren sing. By pressing the key m, the outer series of apertures in the cylinder c is opened, and by working the bellows, the air is caused to impinge against the disk. It begins to rotate, and you hear a succession of puffs which follow each other so slowly that they may be counted. But as the motion augments, the puffs succeed each other with increasing rapidity, and at length you hear a deep musical note. As the velocity of rotation increases the note rises in pitch; it is now very clear and full, and as the air is urged more vigorously, it becomes so shrill as to be painful. Here we have a further illustration of the dependence of pitch on rapidity of vibration. I touch the side of the disk and lower its speed; the pitch falls instantly. Continuing the pressure the tone continues to sink, erding in the discontinuous puffs with which it began.

Were the blast sufficiently powerful and the siren sufficiently free from friction, it might be urged to higher and higher notes, until finally its sound would become inaudible to human ears. This, however, would not

prove the absence of vibratory motion in the air; but would rather show that our auditory apparatus is incompetent to take up and translate into sound vibrations whose rapidity exceeds a certain limit. The ear, as we shall immediately learn, is in this respect similar to the eye.

By means of this siren we can determine with extreme accuracy the rapidity of vibration of any sonorous body. It may be a vibrating string, an organ-pipe, a reed, or the human voice. Operating delicately, we might even determine from the hum of an insect the number of times it flaps its wings in a second. I will illustrate the subject by determining in your presence a tuning-fork's rapidity of vibration. From the acoustic bellows I urge the air through the siren, and, at the same time, draw my bow across the fork. Both now sound together, the tuning-fork yielding at present the highest note. But the pitch of the siren gradually rises, and at length you hear the "beats" so well known to musicians, which indicate that the two notes are not wide apart in pitch. These beats become slower and slower; now they entirely vanish, both notes blending as it were to a single stream of sound.

All this time the clockwork of the siron has remained out of action. As the second-hand of a watch crosses the number 60, the clockwork is set going by pushing the button a. We will allow the disk to continue its rotation for a minute, the tuning-fork being excited from time to time to assure you that the unison is preserved. The second-hand again approaches 60; as it passes that number the clockwork is stopped by pushing the button b; and then, recorded on the dials, we have the exact number of revolutions performed by the disk. The number is 1,440. But the series of holes open during the experiment numbers 16; for every revolution, therefore, we had 16 puffs of air, or 16 waves of sound. Multiply-

Fig. 29.

ing 1,440 by 16, we obtain 23,040 as the number of vibrations executed by the tuning-fork in a minute. Dividing this by 60, we find the number of vibrations executed in a second to be 384.

§ 12. *Helmholtz's Double Siren.*

Prof. Dove, as we have seen, extended the utility of the siren of Cagniard de la Tour, by providing it with four series of orifices instead of one. By doubling all its parts, Helmholtz has recently added vastly to the power of the instrument. The double siren, as it is called, is now before you, Fig. 29 (next page). It is composed of two of Dove's sirens, c and c', one turned upside down. You will recognize in the lower siren the instrument with which you are already acquainted. The disks of the two sirens have a common axis, so that when one disk rotates the other rotates with it. As in the former case, the number of revolutions is recorded by clockwork (omitted in the figure). When air is urged through the tube t' the upper siren alone sounds; when urged through t, the lower one only sounds; when it is urged simultaneously through t' and t, both the sirens sound. With this instrument, therefore, we are able to introduce much more varied combinations than with the former one. Helmholtz has also contrived a means by which not only the disk of the upper siren, but the box c' above the disk, can be caused to rotate. This is effected by a toothed wheel and pinion, turned by a handle. Underneath the handle is a dial with an index, the use of which will be subsequently illustrated.

Let us direct our attention for the present to the upper siren. By means of an India-rubber tube, the orifice t' is connected with an acoustic bellows, and air is urged into c'. Its disk turns round, and we obtain with it all the results already obtained with Dove's siren. The pitch of the note is uniform. Turning the handle above, so as to cause the orifices of the cylinder c' to
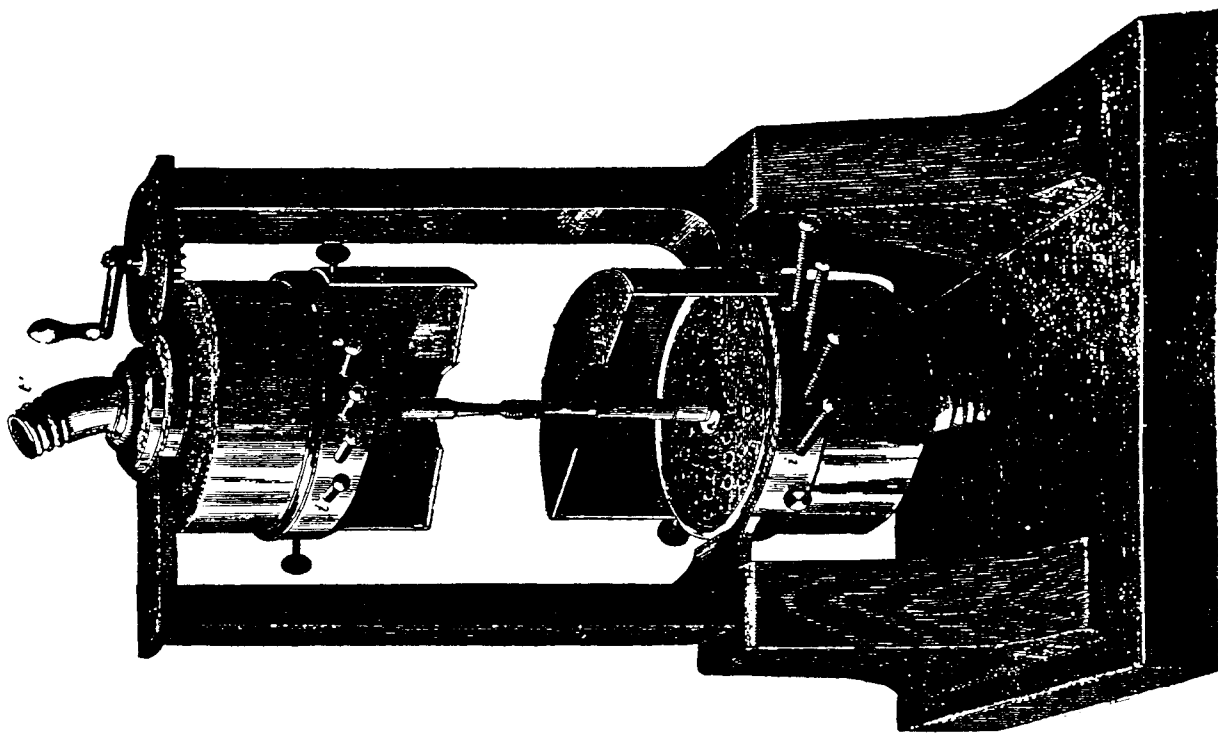
meet those of the disk, the two sets of apertures pass each other more rapidly than when the cylinder stood still. An instant rise of pitch is the result. By reversing the motion, the orifices are caused to pass each other

more slowly than when c' is motionless, and in this case you notice an instant fall of pitch when the handle is turned. Thus, by imparting in quick alternation a right-handed and left-handed motion to the handle, we obtain successive rises and falls of pitch. An extremely instructive effect of this kind may be observed at any railway station on the passage of a rapid train. During its approach the sonorous waves emitted by the whistle are virtually shortened, a greater number of them being crowded into the ear in a given time. During its retreat we have a virtual lengthening of the sonorous waves. The consequence is, that, when approaching, the whistle sounds a higher note, and when retreating it sounds a lower note, than if the train were still. A fall of pitch, therefore, is perceived as the train passes the station.' This is the basis of Doppler's theory of the colored stars. He supposes that all stars are white, but that some of them are rapidly retreating from us, thereby lengthening their luminiferous waves and becoming red. Others are rapidly approaching us, thereby shortening their waves, and becoming green or blue. The ingenuity of this theory is extreme, but its correctness is more than doubtful.

On the 8th of October another instrument, which has played a specially important part in these observations, was introduced. This was a steam-siren, constructed and patented by Mr. Brown of New York, and introduced by Prof. Henry into the lighthouse system of the United States. As an example of international courtesy worthy of imitation, I refer with pleasure to the fact that when informed by Major Elliot of the United States Army that our experiments had begun, the Lighthouse Board at Washington, of their own spontaneous kindness, forwarded to us for trial a very noble instrument of this description, which was immediately mounted at the South Foreland.

In the steam-siren, as in the ordinary one, described in Chapter II., a fixed disk and a rotating disk are employed, but radial slits are used instead of circular apertures. One disk is fixed vertically across the throat of a conical trumpet $16\frac{1}{4}$ feet long, 5 inches in diameter where the disk crosses it, and gradually opening out till at the other extremity it reaches a diameter of 2 feet 3 inches. Behind the fixed disk is the rotating one, which is driven by separate mechanism. The trumpet is connected with a boiler. In our experiments steam of 70 lbs. pressure was for the most part employed. Just as in the ordinary siren, when the radial slits of the two disks coincide, and then only, a strong puff of steam escapes. Sound-waves of great intensity are thus sent through the air, the pitch of the note depending on the velocity of rotation. (A drawing of the steam-siren constitutes our frontispiece.)

"Ancient Indian Airship Technology"
from The Anti-Gravity Handbook
by David Hatcher-Childress

There seems to be no doubt that Vimanas were powered by some sort of "anti-gravity." Vimanas took off vertically, and were capable of hovering in the sky, like a modern helicopter or dirigible. Bharadvajy the Wise refers to no less than 70 authorities and 10 experts of air travel in antiquity. These sources are now lost.

Vimanas were kept in a Vimana Griha, a kind of hanger, and were sometimes said to be propelled by a yellowish-white liquid, and sometimes by some sort of mercury compound, though writers seem confused in this matter. It is most likely that the later writers on Vimanas, wrote as observers and from earlier texts, and were undestandably confused on the principle of their propulsion. The "yellowish-white liquid" sounds suspiciously like gasoline, and perhaps Vimanas had a number of different propulsion sources, including combustion engines and even "pulse-jet" engines. It is interesting to note, that the Nazis developed the first practical pulse-jet engines for their V-8 rocket "buzz bombs." Hitler and the Nazi staff were exceptionally interested in ancient India and Tibet and sent expeditions to both these places yearly, starting in the 30's, in order to gather esoteric evidence that they did so, and perhaps it was from these people that the Nazis gained some of their scientific information!

"It would of course be a great step forward if we succeeded in combinining the gravitational field and the electro-magnetic field into a single structure. Only so could the era in theoretical physics inaugurated by Faraday and James Clerk Maxwell be brought to a satisfactory close."

--Albert Einstein
Mein Weltbild
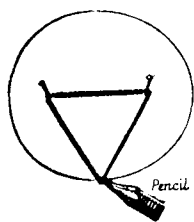
Pencil

JAMES CLERK MAXWELL

Take two thumb tacks and stick them, say, two inches apart, into a piece of paper. Join the pins by fastening a length of thread to them but leave plenty of slack as in the illustration. Now, with a pencil point, stretch the thread taut and draw a line on the paper keeping the string tight.

When he was fourteen, "Dafty" Maxwell invented this method of constructing a perfect ellipse. His father accompanied him to the meeting of the Royal Society of Edinburgh where this mathematical discovery was read by a university professor.

It is not for this ingenious method of drawing an ellipse, but for his scientific and mathematical formulations that we remember James Clerk Maxwell. His treatise *A Dynamical Theory of the Electromagnetic Field* appeared in 1865. This treatise proved to be the key that unlocked the door to radio, television, radar, and all devices that depend upon the generation and control of electromagnetic waves. Maxwell remains enthroned with Newton and with Einstein as a mathematical physicist without superior.

The truly brilliant Maxwell was born on November 13, 1831, in Edinburgh, Scotland. His family was well established and was known, not only for its many accomplished and successful members, but also for their eccentric personalities. James's father, trained for the law, did not care to practice but looked after his small estates and devoted himself to the education of his son. The boy's interest in mechanical devices was encouraged by his father. James early showed his own insatiable curiosity. He wanted to know why, and how, any mechanical contrivance worked. Like many boys of today he made mechanical devices and models. But then there were no hobby shops in which to buy the parts, he had to make his models from the ground up.

James's mother died when he was nine years old. His father, with the help of a maiden aunt, drew closer to the boy in an effort to make up for this great loss. At age ten, James was sent to the Edinburgh Academy, all dressed up in clothes his father had designed for him, even to the square-toed shoes. We may well imagine that Maxwell had a tough time of it. He was someone his schoolmates could pick on, and they did — until his brilliance won them over. Even so, they called him "Dafty."

When James was sixteen he entered the University of Edinburgh. He was already a brilliant mathematician and became absorbed in scientific experiments of all kinds. He liked to write poetry, which he did badly but enjoyed throughout his life.

In 1850 Maxwell left Scotland to study at the University of Cambridge. He was coached in mathematics by William Hopkins in preparation for a competition in which only the best math students competed. Hopkins is quoted as saying of Maxwell, "It appears impossible for him to think incorrectly on physical subjects." But Maxwell took only second place in the competition. Maxwell was promptly elected to the Apostles, a club consisting of the twelve outstanding students at Cambridge.

He must have been a nuisance to his dormitory companions, however. He had some original notions about sleep. He divided each 24 hours into two periods of sleep and wakefulness and he chose to exercise from two to two-thirty in the morning by running up and down the corridors.

Maxwell got his degree in 1854 but decided to stay on to study at Trinity College, Cambridge. His studies led to his invention of a color top to demonstrate that suitable combinations of the three primary colors, red, green, and blue — could produce practically every color imaginable. His scientific paper describing this investigation is the basis for the color in television; all the colors of this modern device are produced by combinations of red, green, and blue. His studies on color won the Rumford Medal of the Royal Society.

His father was ailing and James wished to return to Scotland to be close at hand. He obtained the chair of science at Marischal College in Aberdeen, but unhappily his father died a few days before he was to start this new position.

The average student did not benefit very greatly from Professor Maxwell's instructions; only the bright ones were able to follow his teaching. But Maxwell did profit from his position. He found his wife at Marischal College, the daughter of the head of the college. He wrote to his aunt, "She is not mathematical, but there are other things beside that, and she certainly won't interefer with mathematics." These few lines disclose the basic good humor and pleasantness of this great genius.

Maxwell had done some original and important work on a mathematical analysis of Saturn's rings and on the movements of gases. His mathematical analysis and his physical model of the movement and collisions of particles of gas have stood the test of time and are still in use despite the many changes that modern science has brought. But Maxwell's work in the theory of electricity and magnetism far overshadows his other work.

He was intrigued by Faraday's theory of electromagnetic induction, the production of electricity from magnetism. In his explanation, Faraday had used the term "lines of force" or "tubes of force" to describe the space around a magnet. Maxwell developed, in his mind, a model of the magnetic field. The model consisted essentially of rotating cylinders separated by small spheres like ball bearings. When one cylinder was turned the motion was transmitted through the spheres so that all cylinders would turn. From these models he was able to develop four basic ideas, which look very simple:

A magnetic line of force is a closed line, that is it forms a loop without end.

An electric line of force is also a closed line; it too forms a loop and returns on itself.

A changing magnetic field creates an electric field.

A changing electric field creates a magnetic field.

Faraday had established that a changing magnetic field would produce an electric current in a conductor, but Maxwell had deduced that a changing magnetic field could produce an electric effect in space, and a change in an electric field could produce a magnetic effect. Maxwell went further, his equations showed that it would take *time* for these electric and magnetic effects to travel. He showed they would travel with the speed of light and would travel together.

Ten years after Maxwell's death, Heinrich Hertz proved Maxwell's electromagnetic theory by setting up the first
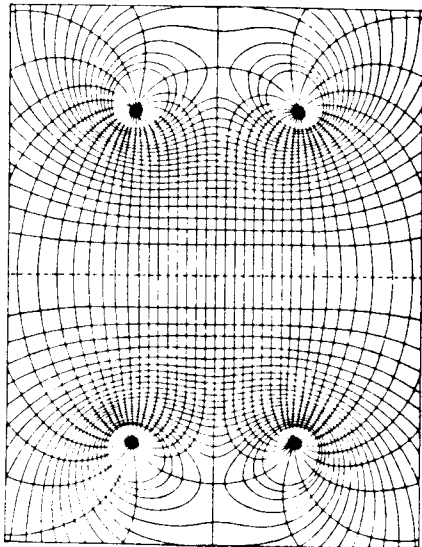
Maxwell's lines of force.

radio transmitter and receiver. Seventy-five years after Maxwell's death, electronic engineers and experimenters study Maxwell's equations as the key to the understanding of radar and microwaves. We know now that Maxwell showed that all electromagnetic waves follow the same basic laws, whether the waves are heat or light or radio or X rays or gamma rays.

For a time Maxwell retired to his estate at Glenair to finish his work on electromagnetic theory. He wrote textbooks on heat, mathematics, color vision and physics. He was fond of his neighbors, played with their children, went to Cambridge occasionally to act as an examiner, and wrote poetry.

In 1871 pressure was brought to bear on the authorities at Cambridge to set up a chair in experimental physics, so that the new subjects of interest to the times — heat, electricity and magnetism — might be introduced at Cambridge. The Duke of Devonshire, Chancellor of the University and member of the family of Henry Cavendish, contributed the money for the building and furnishing of the Cavendish Laboratory. Maxwell was persuaded to accept the chair of experimental physics, which also entailed supervising the building and equipping of the new laboratory.

Maxwell continued to write on various subjects. He also did a monumental job of editing the papers of Henry Cavendish, thus belatedly giving Cavendish credit for important work in electricity.

The last two years of Maxwell's life were devoted to caring for his invalid wife, although he too was ailing. Aware of the fatal nature of his illness, cancer, he did not consult doctors or tell his friends of his condition for some time. A patient, kindly, selfless man, his wit and humor were soon lost in suffering. He died on November 5, 1879, before he was forty-eight years old.

Mankind has still not exhausted all that his imagination and mathematics foresaw. Many still undiscovered inventions will owe much to the genius of James Clerk Maxwell. His equations had predicted the discovery of the radio spectrum, and X rays and gamma rays which led to an understanding of the atom.

Maxwell showed how electricity can produce magnetism. A current in the ring produces a magnetic field around the bar.

MAXWELL'S DEMON

This hypothetical being, invoked by James Clerk Maxwell nearly a century ago as a violator of the second law of thermodynamics, has occupied the minds of many prominent physicists ever since

by W. Ehrenberg

One of the best established facts in thermodynamics is that it is impossible in a system enclosed in an envelope which permits neither change of volume nor passage of heat, and in which both the temperature and the pressure are everywhere the same, to produce any inequality of temperature or of pressure without the expenditure of work. This is the second law of thermodynamics, and it is undoubtedly true as long as we can deal with bodies only in mass, and have no power of perceiving or handling the separate molecules of which they are made up. But if we conceive a being whose faculties are so sharpened that he can follow every molecule in its course, such a being, whose attributes are still as essentially finite as our own, would be able to do what is at present impossible to us. For we have seen that the molecules in a vessel full of air at uniform temperature are moving with velocities by no means uniform, though the mean velocity of any great number of them, arbitrarily selected, is almost exactly uniform. Now let us suppose that such a vessel is divided into two portions, A and B, by a division in which there is a small hole, and that a being, who can see the individual molecules, opens and closes this hole, so as to allow only the swifter molecules to pass from A to B, and only the slower ones to pass from B to A. He will thus, without expenditure of work, raise the temperature of B and lower that of A, in contradiction to the second law of thermodynamics.

―James Clerk Maxwell

For nearly a century the "demon" invoked by Maxwell in the foregoing passage has haunted the world of physics. This hypothetical being makes his appearance under the heading "Limitation of the Second Law of Thermodynamics" near the end of Maxwell's book *Theory of Heat*, published in 1871.

How seriously Maxwell took his demon is hard to say. In any case, he neither carried out nor promoted experiments to test his hypothesis. His almost offhand remark has nonetheless intrigued many prominent physicists, because it holds out the possibility of a perpetual-motion machine deriving its mechanical effect from the temperature difference between the two portions of the vessel.

As it happens, there is an easier way to design a perpetual-motion machine that employs the services of such a sorting demon. Beginning with equal pressures and temperatures on each side of the division, the demon could, by opening and closing the shutter at the right times, allow molecules to pass only from portion A to portion B. This would eventually result in a difference in pressure between the two sides, a situation that would be even more adaptable than a difference in temperature.

JAMES CLERK MAXWELL (1831-1879) put forward his idea of the sorting demon in a brief remark that appears near the end of his book *Theory of Heat*, published in 1871.
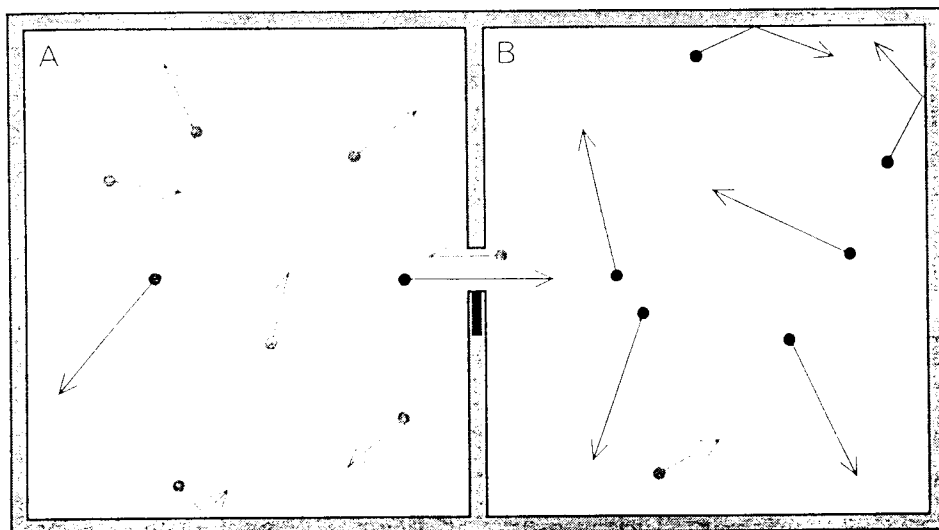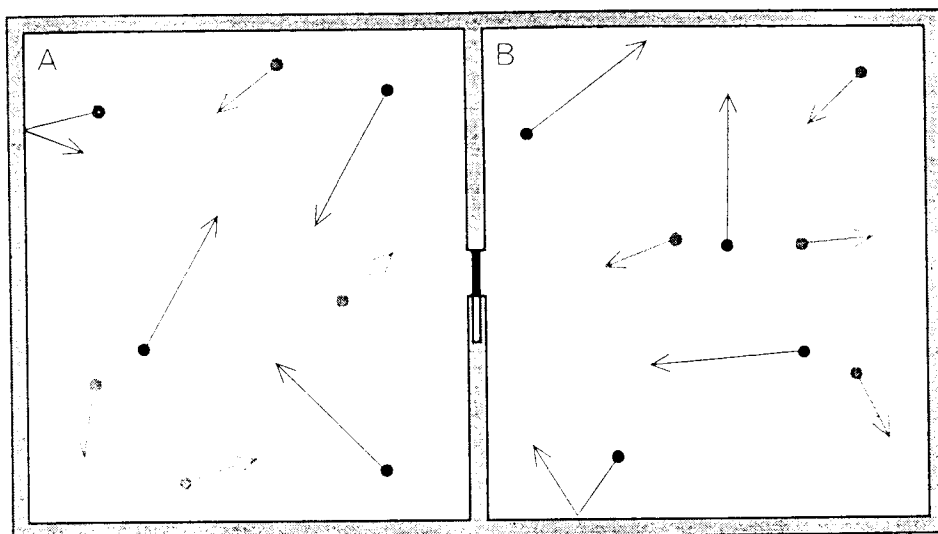
SORTING DEMON OPERATES by opening and closing a small hole in a division between two portions of a vessel full of air at a uniform temperature (*top*). The demon can see the individual molecules, which move at many different velocities. By opening and closing the hole so as to allow only the swifter molecules to pass from *A* to *B* and only the slower ones to pass from *B* to *A*, the demon could, without expenditure of work, raise the temperature of *B* and lower that of *A* (*bottom*), in contradiction to the second law of thermodynamics. It would then be an easy matter to design a perpetual-motion machine that derived its mechanical effect from the temperature difference between the two portions of the vessel.
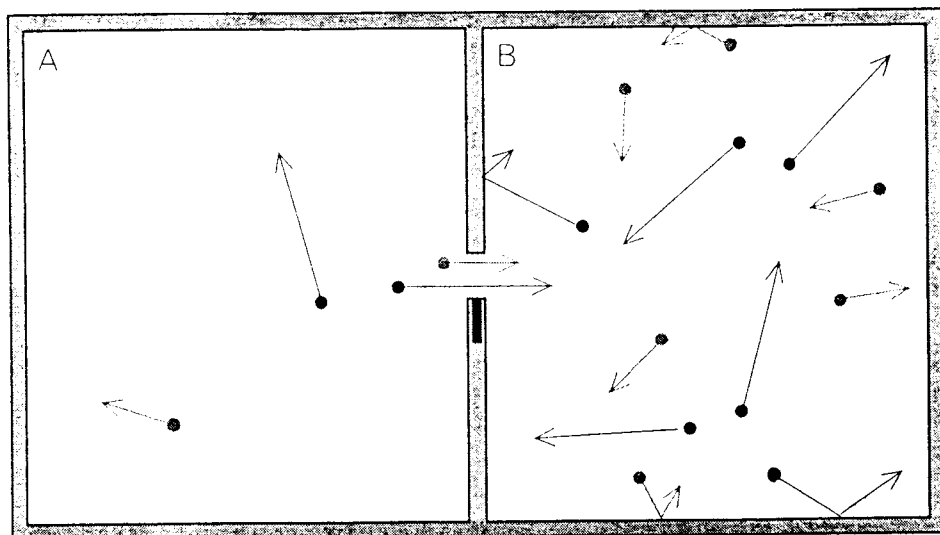
ANOTHER APPROACH to the problem of designing a perpetual-motion machine that employs the services of a sorting demon also begins with equal pressures and temperatures on both sides of the division. By opening and closing the shutter at the right times the demon could allow both swift and slow molecules to pass only from *A* to *B*. The resulting difference in pressure between the two sides could then be readily translated into mechanical work.

The purpose of this article is to review the various turns Maxwell's idea has taken since 1871. It is an idea that should not be discarded lightly. A practical system with immunity from the second law of thermodynamics would be the ultimate prime mover, capable of returning the fuel after the work is done. Undoubtedly such a system would have economic consequences far greater than, say, nuclear power, and a few decades ago a nuclear power station would have been considered a project equally fantastic.

Ed. note: this eight-page article, as well as the nine-page 1987 article excerpted below, start out painting a rosy picture for a new world of free energy if Maxwell's Demon were possible. Then they launch into long, abstract arguments on issues peripheral, at best, to air engines.

The second law was worded much more cautiously by William Thomson (Lord Kelvin) in 1851. "It is impossible," he wrote, "by means of an inanimate material agency, to derive mechanical effect from any portion of matter by cooling it below the temperature of the coldest of the surrounding objects." The phrase "inanimate material agency" is noteworthy here. It is not merely Thomson's term for Clausius' "self-acting machine." This Thomson made quite clear by adding: "The animal body does not act as a *thermodynamic engine*. The means in the animal body by which mechanical effects are produced cannot be arrived at without more experiment and observation.... Whatever the nature of these means, consciousness teaches every individual that they are, to some extent, subject to the direction of his will. It appears therefore that animated creatures have the power of immediately applying to certain moving particles of matter within their bodies, forces by which the motion of these particles are directed to produce desired mechanical effects."

Maxwell's remark about the demon gave these general reservations of Thomson's new force by relating them to the results of the new kinetic theory of gases, which treated the thermodynamic properties of a gas in terms of the average motions of its constituent particles. This led Thomson to comment: "The definition of a demon, according to the use of this word by Maxwell, is an intelligent

Demons, Engines and the Second Law

Since 1871 physicists have been trying to resolve the conundrum of Maxwell's demon: a creature that seems to violate the second law of thermodynamics. An answer comes from the theory of computing

by Charles H. Bennett

One manifestation of the second law of thermodynamics is that such devices as refrigerators, which create inequalities of temperature, require energy in order to operate. Conversely, an existing inequality of temperature can be exploited to do useful work—for example by a steam engine, which exploits the temperature difference between its hot boiler and its cold condenser. Yet in 1871 the Scottish physicist James Clerk Maxwell suggested, in his *Theory of Heat*, that a creature small enough to see and handle individual molecules might be exempt from this law. It might be able to create and sustain differences in temperature without doing any work:

"...if we conceive a being whose faculties are so sharpened that he can follow every molecule in its course, such a being, whose attributes are still as essentially finite as our own, would be able to do what is at present impossible to us. For we have seen that the molecules in a vessel full of air at uniform temperature are moving with velocities by no means uniform.... Now let us suppose that such a vessel is divided into two portions, A and B, by a division in which there is a small hole, and that a being, who can see the individual molecules, opens and closes this hole, so as to allow only the swifter molecules to pass from A to B, and only the slower ones to pass from B to A. He will thus, without expenditure of work, raise the temperature of B and lower that of A, in contradiction to the second law of thermodynamics."

The "being" soon came to be called Maxwell's demon, because of its far-reaching subversive effects on the natural order of things. Chief among

these effects would be to abolish the need for energy sources such as oil, uranium and sunlight. Machines of all kinds could be operated without batteries, fuel tanks or power cords. For example, the demon would enable one to run a steam engine continuously without fuel, by keeping the engine's boiler perpetually hot and its condenser perpetually cold.

To protect the second law, physicists have proposed various reasons the demon cannot function as Maxwell described. Surprisingly, nearly all these proposals have been flawed. Often flaws arose because workers had been misled by advances in other fields of physics; many of them thought (incorrectly, as it turns out) that various limitations imposed by quantum theory invalidated Maxwell's demon.

The correct answer—the real reason Maxwell's demon cannot violate the second law—has been uncovered only recently. It is the unexpected result of a very different line of research: research on the energy requirements of computers.

Since Maxwell's day numerous versions of the demon have been proposed. One of the simplest creates a pressure difference (rather than a temperature difference) by allowing all molecules, fast or slow, to pass from B to A but preventing them from passing from A to B. Eventually most of the molecules will be concentrated in A and a partial vacuum will be created in B. This demon is if anything more plausible than Maxwell's original demon, since it would not need to be able to see or think. It is not immediately evident why such a demon—a one-way valve for molecules—could not be realized as some

simple inanimate device, for instance a miniature spring-loaded trapdoor.

Like Maxwell's original demon, the "pressure demon" could be a source of limitless power for machines. For example, pneumatic drills of the kind used to cut holes in streets generally run on compressed air from a tank kept full by a gasoline-powered compressor. A one-way valve for air molecules could substitute for the compressor, effortlessly collecting air from the surroundings into the high-pressure tank.

One might think such an arrangement would violate the law of conservation of energy (otherwise known as the first law of thermodynamics), but it would not. The energy for cutting concrete could be taken from heat in the air collected by the one-way valve; the air's temperature would drop as it passed through the machinery. There is nothing in the first law to prevent an engine from supplying all its energy needs from the ambient heat of its environment, or even from the waste heat of its own friction and exhaust. It is the second law that prohibits such engines.

To analyze the demon's actions closely, then, one must understand some of the subtleties of the second law. The second law was originally expressed as a restriction on the possible transformations of heat and work, but it is now seen as being fundamentally a statement about the increase of disorder in the universe. According to the second law, the entropy, or disorder, of the universe as a whole cannot be made to decrease. This means that only two kinds of events are possible: events during which the entropy of the universe increases and events during which it remains constant. The former are
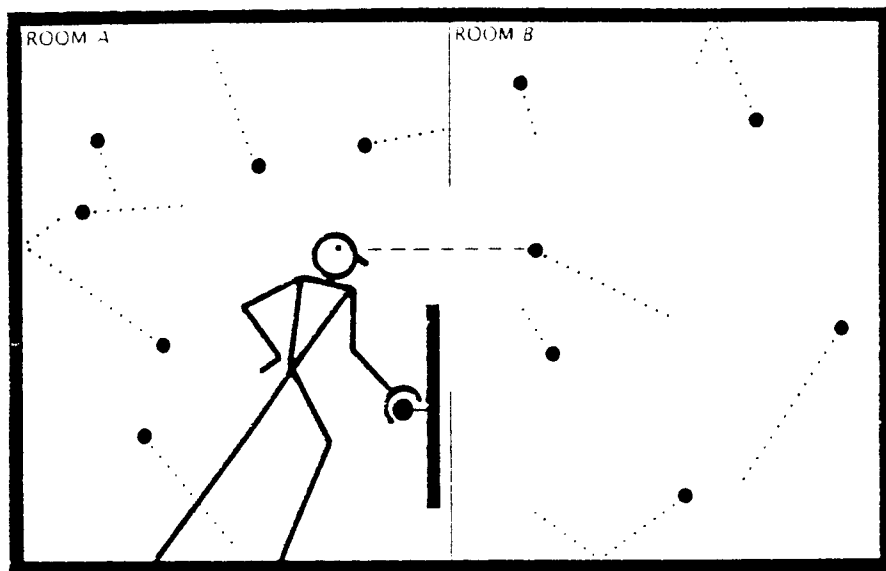
MAXWELL'S DEMON, described in 1871 bv James Clerk Maxwell, seems able to violate the second law of thermodynamics. The demon controls a sliding door that blocks a hole in a wall between rooms containing gas at equal temperatures and pressures. It observes molecules approaching the hole and opens and closes the door to allow fast-moving molecules to pass from room A to room B but not vice versa. Slow-moving molecules, conversely, are allowed to pass only from B to A. As the demon sorts, B heats up and A cools. According to the second law, a certain amount of work is required to create a temperature difference, but the work of sliding a door can be made negligibly small.

known as irreversible processes because to undo them would violate the second law: the latter are called reversible processes. One can decrease the entropy of a given system by doing work on it, but in doing the work one would increase the entropy of another system (or that of the first system's environment) by an equal or greater amount.

A classic irreversible process, and one that helps in defining the concept of entropy a little more precisely, is called free expansion. Suppose a chamber filled with gas is separated by a partition from a vacuum chamber of the same size. If a small hole is made in the partition, gas will escape (that is, it will expand freely) into the formerly empty chamber until both chambers are filled equally.

The reason the molecules spread out to fill both chambers is mathematical rather than physical, if such a distinction can be made. The numbers of molecules on the two sides of the partition tend to equalize not because the molecules repel one another and move as far apart as possible, but rather because their many collisions with the walls of the container and with one another tend to distribute them randomly throughout the available space, until about half of them are on one side of the partition and about half are on the other side.

Since the spreading of the mole-cules is due to chance rather than to repulsion, there is a chance that all the molecules might return simultaneously to the chamber from which they came. If there are n molecules, however, the probability of all of them returning to their original chamber is the same as the probability of tossing n coins and having them all come up "heads": $1/2^n$. Thus for any sizable number of molecules (and there are about 300,000,000,-000,000,000,000,000 molecules in a gram of hydrogen) the free expansion is an effectively irreversible process: a process whose spontaneous undoing, although possible, is so unlikely that one can say with confidence it will never be observed.

The disordered state—the state in which the gas has spread into both chambers rather than residing compactly in a single chamber—is more probable than the ordered state. That is, there are more configurations of molecules in which the molecules occupy both chambers, just as, when 100 coins are tossed, there are more ways to achieve a total of 50 heads and 50 tails than there are to achieve 100 heads and no tails. In saving that the entropy of the universe tends to increase, the second law is simply noting that the universe tends to fall into more probable states as time passes.

Can this concept be quantified? In other words, can one say how much the disorder of the gas has increased after it has spread out to fill both chambers? Consider a single molecule in the gas. A molecule that can roam throughout both chambers has twice as many possible positions as a molecule confined to a single chamber: there are twice as many ways for a molecule to occupy the two-chamber apparatus. If there are two molecules in the two-chamber apparatus, each molecule has twice as many possible positions as it would have in a single chamber, and so the system as a whole has 2×2, or four, times as many possible configurations. If there are three molecules, the system has $2 \times 2 \times 2$, or eight, times as many possible configurations.

In general, if there are n molecules in the gas, the gas can fill two chambers in 2^n times more ways than it can fill a single chamber. The gas in the two-chamber apparatus is said to have 2^n times as many "accessible states" as the gas in a single chamber. In the same way, the number of accessible states in most systems depends exponentially on the number of molecules.

The entropy of a system is therefore defined as the logarithm of the number of accessible states. In the example of the two-chamber gas apparatus, a 2^n-fold increase in the number of accessible states is an increase in entropy of n bits, or binary units. (The base of the logarithm—and hence the size of a unit of entropy—is arbitrary; it is conventional to choose base 2 and binary units.) The logarithmic scale has the advantage of making the entropy of a sample of matter, like its energy or mass, roughly proportional to the number of molecules in the sample. One can draw an analogy to a computer memory: an n-bit memory, other things being equal, has size, weight and cost that are roughly proportional to n, although the number of distinct states possible in the memory is 2^n.

The earliest statements of the second law did not mention randomness or disorder; they concerned heat, work and temperature. How can these concepts be related to our quantitative definition of entropy? The molecules in any sample of matter are always in motion. The speed and direction of each molecule are random, but the average speed of the molecules is proportional to the square root of the sample's temperature (as measured from absolute

EDITOR'S TABLE

EXPLANATIONS THAT DO NOT EXPLAIN.

THERE is a certain class of minds whose efforts to explain things generally leave them more obscure than they were before. In undertaking to represent a question they complicate rather than simplify it, and instead of helping the learner to understand a subject they hinder him. This failure to make things lucid and comprehensible is due to various causes. Oftenest, it comes from a total neglect of the art of luminous writing, and it is unfortunate that many scientific men are not a little perverse about cultivating this art. They do not, as a matter of conscience, make any effort to enter into the state of mind of the parties addressed, and their expositions, therefore, often fail from lack of adaptation. Sometimes a subject familiar to teachers of great capacity is still too abstruse to be grasped by common minds. Sometimes the expounder does not understand the subject himself; and not unfrequently hypotheses are invented to explain unexplainable things, and which serve only to increase existing difficulties. A marked illustration of this is afforded by a lecture delivered not long ago before the Royal Institution, by the eminent physicist and mathematician, Sir William Thomson, who announced as his topic of discourse the curious subject, "Maxwell's Sorting Demons."

The lecture was mainly devoted to an explication of the phenomena of the diffusion of liquids and the principles it involves. Professor Thomson had many tubes prepared, each containing two liquids of different colors, to represent the progress of diffusion, while some ingenious experiments were made by throwing the spectra of various solutions upon the screen with an electric light. The diffusibility of solids and gases was also referred to, and a just tribute paid to the memory of Graham, whose name stands most prominently associated with this branch of research.

Sir William Thomson's reasons, however, for bringing forward these phenomena of diffusion were that they stand very closely related to the present theories and speculations concerning the molecules of matter, and which aim to account for their motions. In diffusion, the molecules gradually intermingle, according to definite laws, which are variable in different cases. The molecules do not move capricious-

ly or irregularly, as all chemical action and all crystallization prove. But why do they move this way or that, and why always go the same way in the same conditions? This "why" is the perplexing word of science, and when we get down among objects the very existence of which is hypothetical it carries us far beyond our depth. But Professor Maxwell thinks he gives us aid here by inventing a host of little demons—living creatures with wills and infallible intelligence—which sort the molecules and regulate their extraordinary motions. In a very brief abstract of his lecture which Sir William Thomson has published, he thus explains the attributes and offices of these remarkable agents:

> Clerk Maxwell's "demon" is a creature of imagination having certain perfectly well-defined powers of action, purely mechanical in their character, invented to help us to understand the "dissipation of energy" in nature. He is a being with no preternatural qualities, and differs from real living animals only in extreme smallness and agility. He can at pleasure stop, or strike, or push, or pull any single atom of matter, and so moderate its natural course of motion. Endowed ideally with arms and hands and fingers—two hands and ten fingers suffice—he can do as much for atoms as a piano-forte player can do for the keys of the piano—just a little more, he can push or pull each atom *in any direction.*
>
> He can not create or annul energy; but, just as a living animal does, he can store up limited quantities of energy, and reproduce them at will. By operating selectively on individual atoms he can reverse the natural dissipation of energy, can cause one half of a closed jar of air, or of a bar of iron, to become glowingly hot and the other ice cold; can direct the energy of the moving molecules of a basin of water to throw the water up to a height and leave it there proportionately cooled (1° Fahr. for seven hundred and seventy-two feet of ascent); can "sort" the molecules in a solution of salt or in a mixture of two gases, so as to reverse the natural process of diffusion, and produce concentration of the solution in one portion of the water, leaving pure water in the remainder of the space occupied; or, in the other case, separate the gases into different parts of the containing vessel.
>
> The classification, according to which the ideal demon is to sort them, may be according to the essential character of the atom : for instance, all atoms of hydrogen to be let go to the left, or stopped from crossing to

the right, across an ideal boundary; or it may be according to the velocity each atom chances to have when it approaches the boundary : if greater than a certain stated amount, it is to go the right; if less, to the left. This latter rule of assortment, carried into execution by the demon, disequalizes temperature, and undoes the natural diffusion of heat : the former undoes the natural diffusion of matter.

This looks to us like a somewhat ridiculous way of evading the real difficulties in the explanation of molecular motions and their effects. All nature is supposed to be filled with infinite swarms of absurd little microscopic imps, which are so omniscient that they direct the invisible and insensible movements by which the whole order of nature is determined and maintained. When men like Maxwell, of Cambridge, and Thomson, of Glasgow, lend their sanction to such a crude hypothetical fancy as that of little devils knocking and kicking the atoms this way and that, in order to explain the observed changes of natural phenomena, we may well ask, What next? This is a palpable case of contriving an artifice to explain a subject which yet leaves the subject more obscure than ever. There were difficulties enough with the molecules considered alone, but when complicated with another hypothetical order of beings the difficulties are redoubled, for we have now to explain the explanation. There is a great proneness to invent explanations which only remove the trouble one step further away. Sir William Thomson's hypothesis of the origin of terrestrial life by means of germs, brought to our planet from some unknown source by meteorites, is another example of explanations by assumptions, in which nothing is explained. There is a class of scientific men who feel it incumbent upon them to answer all questions. They do not seem to appreciate the fact that there are limits to our knowing, which had better be honestly acknowledged, instead of offering conjectures which are mere travesties of legitimate theory, and absurdities in science.

CRANKS IN PERPETUAL MOTION

Perhaps the most ingenious p.m. fallacy ever proposed was that of the physicist James Clark Maxwell, a device known for a century as Maxwell's Demon. As proposed in his *Theory of Heat*, 1871, it seemed perfectly sound in theory, and yet it violated the Second Law of Thermodynamics, the law of increased entropy.

Maxwell imagined a box divided into two compartments, both filled with air. In the wall between the two is a tiny door, just big enough, when open, to let through a single molecule of air. At this door is posted a tiny creature who can open the door, when he chooses, to allow a molecule to pass through.

Now, suppose this demon opens the door whenever a molecule approaches in compartment A, allowing it to pass through to compartment B, but he never allows a molecule from B to return to A. (Maxwell's example was slightly more complicated, but on the same principle.) Eventually compartment B will become crammed with air, compressed to a high pressure, while A will be partly evacuated. The air in B could then be used to power a compressed-air engine, and the exhaust returned to A, to start over again. The demon and his door are so tiny that the energy they might require could more than be supplied by the engine.

Physicists from 1871 to 1951 argued about Maxwell's Demon. For a time it was thought that the animate intelligence of the demon (in deciding when to open and shut the door) was itself a violation of entropy, and Lord Kelvin proposed that human intelligence, too, violates entropy. But by now few biologists (aside from Teilhard) believe that humans are in any way exempt from the increasing disorder that affects, so far as we know, the rest of the universe.

Finally Maxwell's Demon was defeated by rather sophisticated arguments involving information theory, by Leon Brillouin in 1951. An explanation of his arguments may be found in a *Scientific American* offprints.[8]

Understanding Thermodynamics

It has not been necessary in our discussions of thermodynamics to mention the nature of matter, nor is it *necessary* now. As far as classical thermodynamics is concerned, matter may as well not be made up of atoms. But our belief in atoms and molecules is pretty firm, and we gain nothing by ignoring the atomistic nature of matter. It makes much more sense to ask what can be added to thermodynamics by knowing something of the structure of matter. This type of inquiry has led to the development of kinetic theory and statistical mechanics. It is sometimes said that the development of thermodynamics preceded the development of those subjects which rely on the atomic nature of matter. But this

is hardly true, for to a considerable degree they developed simultaneously, often in the minds of the same individuals. The first book on applied thermodynamics was published by Rankine in 1859, the same year that Maxwell published his first paper on the dynamical theory of gases. Thermodynamics, kinetic theory, and statistical mechanics after 1850 grew up together and eventually led to the quantum theory. It is often forgotten that Max Planck took thermodynamics and statistical mechanics as his special fields of interest, and it was difficulties that arose in these fields that led him to the postulate that energy is quantized.

Thus questions about the interrelation between thermodynamics and molecular behavior arose very early, and perhaps the most famous problem of this nature was posed by Maxwell in 1871 under the heading "Limitations of the Second Law." He invented (in his mind) a *being* that could

deal directly with molecules; this being has since been known as Maxwell's demon. Maxwell suggested that a container filled with gas be divided by a partition in which there was a trap door manned by his demon. The demon would observe molecules approaching the trap door from both sides and would operate the door so as to allow only fast molecules to pass in one direction and only slow molecules to pass in the other direction. Thus the demon would act to sort molecules according to speed. As a result the gas on one side of the partition would become increasingly warmer and that on the other side cooler. At some point we could start a heat engine to operate between the two temperatures, and it could deliver work continuously to the surroundings as long as the demon continued his activities. It would only be necessary to add heat to the system to compensate for the work done, and we would have an engine operating in a cycle that converted all the heat taken in into work, in violation of the Second Law. Maxwell imagined that his demon itself did no work; it was a reversible demon that released energy to open a frictionless trap door and recovered the same energy when the door closed.

There have been many suggestions as to how to build a device to violate the Second Law, but not one has ever been demonstrated to do so. However, Maxwell added a new dimension to this endeavor. He postulated a being, intelligent in some sense, that could deal with individual molecules. The easiest way out is to declare that the Second Law denies that such a being could exist. But life has always been mysterious, and we inevitably suppose that it must have qualities not fully taken into account by the known laws of physics. After all, bacteria are very small beings whose accomplishments are by no means inconsequential. So Maxwell's demon has not been lightly dismissed, and even after almost 100 years it is still a fascinating topic of discussion. I might remark that a demon that sorts molecules according to speed is not the only demon one can imagine. Sorting on molecular species is another example, but the problem with respect to the Second Law is no different.

Maxwell's demon appears to violate the Second Law through its ability to deal with individual molecules. Is this the key to "success," or are there other ways to take advantage of the molecular nature of matter in efforts to violate the Second Law? Let me pose another problem. Suppose again we have a container divided by a partition. This time there is gas on one side of the partition, but a total vacuum on the other. The partition is removed and the gas expands to fill the total volume. Now the question is whether the gas will ever of its own accord return to its initial location in one part of the container. The overwhelming consensus of informed opinion is that it will, provided one waits long enough! It comes down to a matter of chance. Since the gas molecules are in continual motion, one concludes that there is a finite (but minuscule) probability, a chance, at any instant that the original configuration will

be reproduced. One need not even insist on a special initial configuration. It is sufficient to consider the container merely filled with gas and then to ask whether the gas will ever momentarily collect itself in any portion of the container. For if it does, then we can insert a partition and trap the gas in a state of lower entropy than it had initially. Again the overwhelming consensus of informed opinion is that this is possible if one is prepared to wait long enough, say, $10^{10^{10}}$ years. Whether or not you believe this will ever happen is not important. We can imagine it to happen regardless of whether it actually will, and whether real or imaginary, it represents a process seemingly at odds with the Second Law, and one that does not require dealing with individual molecules. It is important to note, however, that to accomplish the process one must insert a partition into the container at exactly the right instant. Thus the process does require continuous observation of the system by some being or device capable of detecting molecules and taking appropriate action. So we see that the two hypothetical processes just described do have common elements and need not be considered independently.

In particular, they have in common the idea of molecular ordering. In the case of Maxwell's demon ordering is done on the basis of speed; that is, high-speed molecules are segregated from low-speed molecules. In the second case, ordering is done in the sense that molecules are collected from a larger region of space into a more restricted region. This process, by the way, could also be accomplished by a Maxwell demon, one which allowed molecules to pass only one way through its trap door. Another type of ordering process that a Maxwell demon could accomplish results when a gas *mixture* is admitted to the container. The demon could operate his trap door so as to allow green molecules to go only one way and red molecules only the other. This would serve to segregate the green from the red molecules. So you see that our use of the word "ordering" gives it perhaps a broader meaning than is found in its everyday use. Our demon is said to bring about ordering whenever he restricts molecules to a given region of space by virtue of some characteristic of the molecule. We have considered molecular speed, molecular species, and even the very characteristic of being a molecule at all. Molecules left to themselves do not become so ordered except, as we have seen, by chance. Ordering at will requires the intervention of some outside agent, of which Maxwell's demon is a very special example.

All of these ordering processes produce a *reduction* in the entropy of the system, and each reduction can easily be calculated by the methods of thermodynamics. We are therefore led to the notion that increasing order corresponds to decreasing entropy, and vice versa; this is the basic idea that underlies statistical mechanics. All that we need in addition is a method of expressing order or disorder in a quantitative way, but this we will leave for later.

There is another aspect of the sorting processes involving Maxwell demons that we have not yet considered. It centers around the fact that the demon must act on the basis of *information;* that is, he cannot act properly until he knows that a molecule in a particular place is a fast one, a slow one, a red one, a green one, directed left, or directed right, etc. Even a demon that sits around waiting for chance to order a system must keep continuously informed of the locations of molecules; otherwise he would never know the moment to insert a partition so as to preserve the long-awaited but otherwise-momentary order. There are two separate ideas which come out of these observations. The first is that there may be some connection between entropy and information. The second is that the information-gathering activities of the demon may be the key to whether or not he can operate so as to cause violations of the Second Law. The apparent link between information and entropy has been exploited and developed into the subject called *information theory*, which has important applications in the design of communication systems. The fundamental equation of information theory is identical with the equation for entropy in statistical mechanics, and the quantity calculated, having to do with the information content of messages, is even called *entropy*. In statistical mechanics we deduce the properties of matter by applying statistics to large numbers of molecules. In information theory we deduce the information-carrying capacity of communications systems by applying statistics to large numbers of messages.

In our descriptions of the activities and ambitions of Maxwell demons we have implied several questions. Let me state these questions one by one, and provide what are thought to be correct answers:

1. Is it necessary to regard the demon as a *living* being? The answer is that it is not *necessary*. Moreover, it's not even advantageous. The demon is merely an intermediary, a relay mechanism, that responds in a specific way to an information signal. It may therefore be automated or programmed to perform its tasks at least as surely as if it possessed the intelligence of a human being. This is not to deny that an intelligent living being could serve as a sorting demon, but such a demon would be at a disadvantage. In spite of the mysteries of life, every study of life processes has demonstrated that the laws of physics *do* in fact apply. There may be *additional* laws, but none of those known is violated, not even the Second Law of Thermodynamics. The fantastic ordering of atoms and molecules necessary to produce and maintain a living system is accompanied by a more than compensating disorder created in the surroundings. Thus the ever-increasing order represented by increasing numbers of the human species is more than matched by the trail of disorder left in our surroundings, of which the increasing pollution of our atmosphere, rivers, and oceans is

but an example. It is not our problem to explain *how* or *why* the ordering necessary to living systems occurs. The fact is that it does, and it does so without violating the laws of physics. So the attribution of life to Maxwell's demon can only prejudice the case against its ambitions to violate the Second Law. We can therefore narrow our attention to automated devices.

2. Can an automated device be activated by mechanical interaction with the molecules themselves? The answer to this is no, for the following reason. Any device or portion of a device used to trigger the necessary action to accomplish the sorting of molecules can be no more massive than the molecules themselves; otherwise it would grossly interfere with the motions of the molecules and actually prevent the sorting from being accomplished. On the other hand, any object no more massive than the molecules will be subject to the same thermal motions as the molecules, and as a result cannot be held in its proper location. We are therefore reduced to more massive devices which rely on *information* about the molecules to be sorted, and this can be transmitted only by electromagnetic radiation, of which ordinary light is one example.

3. Can an automated device relying on information sort molecules in violation of the Second Law? Again, the answer is that it cannot. We may presume our device to be sufficiently massive and to be mechanically reversible, and we concentrate on the problem of how it is to sense the molecules with which it is designed to deal. The device is enclosed within a container, and the only way it can sense its subject molecules without grossly disturbing their motions is by some form of electromagnetic radiation. Thus the device must radiate energy and sense molecules through their reflection of radiation. This energy is absorbed throughout the system and can be shown to cause a greater entropy increase than any decrease caused by the proper working of the device.

Thus we conclude that Maxwell's demon cannot operate in such a way as to violate the Second Law of Thermodynamics. The fact that this problem has been kicked around for almost 100 years and is still of interest illustrates the reluctance with which even scientists accept the Second Law as being inviolate. There is good reason for *wanting* to violate it, for if it could be done, all of man's energy requirements could forever be met without any depletion of resources or pollution of his surroundings. Man lives on hope, and does not readily take to restrictions on what he can do. So far, however, he has had to live within the limits defined by the laws of thermodynamics, and all indications are that he will continue to.

The Manifestations of Energy

MAXWELL'S DEMON AND THE PUZZLE OF ENTROPY

Today we know that the law of conservation of mass and/or energy still remains one of the strongest of all natural laws. We also know of the wide variety of forms in which energy can be found, and that it is possible to convert energy in one form into energy in another form without loss. A list of the major forms in which energy is encountered would include the following:

Mechanical energy
  Potential energy
  Kinetic energy

Chemical energy

Electrical energy or, more accurately, electromagnetic energy

Heat energy (including heat produced by friction)

Atomic and nuclear energy (including the energy produced when matter is converted into its equivalent amount of energy)

We have seen that it is possible to convert energy from any one of these forms into energy of any other form without ever either creating any new energy (thus increasing the total amount present in the universe) or destroying any energy (thus decreasing the total amount of energy in the universe). In many cases, little or no difficulty is encountered in converting energy from one form to another, and at least theoretically it should be possible to convert 100 per cent of a given amount of energy in one form into any other form desired if the proper technique for accomplishing this is known.

Yet when we get down to the practicalities of actually doing this, we soon discover somewhat surprisingly that here is a case in which nature seems to play favorites. While energy in one form *can* be converted into energy in any other form, it is much more difficult to convert it into certain forms than into certain other forms, while energy in any form seems to be converted so very readily into certain other forms that we have difficulty avoiding those forms and converting it instead into the specific form that we want.

It seems very much as though the various major forms of energy occupy comparatively higher or lower rungs on a ladder, so that it is relatively easy to convert higher forms of energy into lower forms, but exceedingly difficult to convert lower forms of energy into higher forms. And of all forms of energy known, the form that occupies the lowest rung on the ladder—the form of energy that all the other forms can be most readily converted into and the form that is most difficult to convert into any other form—is in many ways the least useful form of energy that we know: *heat energy*.

In fact, energy in the form of heat persistently keeps turning up at times and in places where it is simply not wanted at all. We discussed at some length the conversion of kinetic energy to potential energy and back again, and found that under imaginary ideal conditions 100 per cent of the kinetic energy of a system could be converted to potential energy and then 100 per cent of the potential energy could be converted back to kinetic energy. But any time such a conversion is attempted under *real* conditions, some of the energy involved in each conversion is invariably converted into heat and dissipated into the atmosphere, whether we like it or not. Thus when we have a wheel spinning around an axle, its kinetic energy will gradually be converted to heat and the axle and hub will warm up. Then eventually the axle will cool and the heat energy will be dissipated into the air.

This does not mean, of course, that the energy is lost. It simply means that the air near the wheel becomes a little warmer than it was before—that the molecules of atmospheric gas in the vicinity of the wheel begin moving faster. Those fast molecules will collide with other molecules to set *them* moving faster, or move away from the vicinity of the wheel, so that presently the warmed-up molecules will be mixed with other molecules and disseminated more and more widely. Ultimately the kinetic energy of the wheel "lost" to heat will have been disseminated evenly throughout all of the gaseous atmosphere surrounding the earth and will have served simply to warm that atmosphere up a tiny bit. Similarly, a mechanical device operating under water will lose a certain amount of its mechanical energy to heat which will go to warm up the water in which it is operating. But again, presently, the tiny amount of increase in the water's temperature will warm the atmosphere by a tiny amount.

Other conversions of energy seem to produce the same phenomenon. A great many of the chemical reactions that take place, either in laboratories, in industrial processes, or in the cells of living organisms, result in transformation of a great deal of potentially useful chemical energy into essentially useless heat energy. Nor is the loss always too tiny to measure; recently scientists studying the pollution of rivers and lakes in heavily industrialized areas have discovered that heat-producing industrial processes using river or lake water as a means of getting rid of unwanted heat have in some cases actually raised the temperature of the water in those streams and lakes to such a degree that the normal native plant and animal life can no longer survive. Again, any time electrical energy in the form of electric current passes through one of a variety of substances that offer "resistance," to its passage, part of the electrical energy is converted into heat which will then serve to heat up the air around the substance offering the resistance.

But doesn't this conversion of other forms of energy into heat work just as well the other way? If any form of energy can be converted into any other

form, then it must be possible to convert heat into potential energy or kinetic energy or electrical energy or chemical energy, mustn't it? The answer is a guarded yes, except that it doesn't quite work that way. Heat *can* be converted into other fo_ns of energy, given the right circumstances. We might, for example, use heat to raise a quantity of water to the boiling point, and then use the resultant steam under pressure to produce mechanical energy. This is how a steam engine works, and steam engines certainly have proved to be useful devices in mankind's history. *But they have also proved to be somewhat inefficient machines.* Only about 60 to 70 per cent of the heat energy used to heat the water in the steam engine's boiler ever actually gets converted to mechanical energy. But in the opposite direction, if sufficient friction were present, it would be quite possible and indeed very easy to convert virtually *all* of a given quantity of mechanical energy into heat. In 1852 William Thompson, Lord Kelvin, expressed it very succinctly: "It is impossible to invent an engine which simply takes in heat and converts it entirely into mechanical work." On the other hand, it would be very easy to invent an engine which would take mechanical energy and convert it entirely into heat.

As physicists came to recognize this odd peculiarity about heat energy as compared with other kinds of energy, it became increasingly clear that this was not merely an insignificant curiosity. There seemed to be a definite "natural" direction in which energy sought to flow when it was converted from one form to another, just as there is a "natural" direction in which water seeks to flow. Of course it is possible to force water to run uphill, either by pumping it or by arranging one or another kind of device to thrust or carry it uphill, but it flows uphill only "against its will," so to speak, and in opposition to its "natural" direction of flow. On the other hand, given the slightest opportunity, water will flow downhill without requiring any effort on our part at all.

Similarly, heat energy can be forced "against its will" to be converted into other forms of energy, but only at the cost of a great deal of effort, while other forms of energy can be converted into heat given the slightest opportunity. Ordinarily, heat will always tend to flow from an area of high heat content into an area of lower heat content—from a hot area to a cold area—any time two such areas with different temperatures are side by side. A hot area *can* be heated up further while an adjacent cold area becomes colder, but again only at the cost of a great deal of energy *added* to the system. For example, we could open the door of a household freezer in the middle of a warm room, and then set the controls so that the freezing unit inside the freezer becomes even colder while the door is still open, while the room becomes even warmer as a result of heat being pumped out of the freezing compartment and dissipated into the air. But this would require a very considerable input of additional energy (in this case electrical energy) to operate the freezer. It is certainly not the "natural" way that

heat would tend to move under the circumstances unless it were *forced* to move that way.

Indeed, the "natural" tendency of heat to move from a warm area to an adjacent colder area was soon recognized as a means by which heat energy could be made to do work. In a system in which a quantity of gas with a high heat content (that is, with molecules moving with high kinetic energy) is adjacent to a collection of gas with a low heat content (in which the molecules have a much lower average kinetic energy) physicists thought of the energy in the system as "ordered" to a certain extent because the gas molecules could be made to do work just by leaving them to themselves to intermingle until a state of equilibrium between the "hot" molecules and the "cold" molecules had occurred. In such a state of equilibrium, the system would have become "less ordered" since there was no natural tendency for the hot molecules and the cold molecules to separate themselves out on two sides of the fence again—in other words, since there was no longer any way that the gas molecules could do work when left to themselves.

Physicists use a rather peculiar word to describe the *degree of disorder of* the energy in such a system of hot and cold gases which had been allowed to intermix toward equilibrium: They speak of *entropy* as a measure of the degree of disorder of the energy in such a system. Thus, if we could start with all the hot gas molecules in a container on one side of a partition with a hole in the center, and all the cold molecules on the other side of the partition, the energy of the molecules would be sharply separated or highly "ordered" and the system would have very little entropy. After a while, however, hot gas molecules and cold gas molecules would intermingle through the hole in the partition. The energy in the system would become more and more disordered, which would mean that *the entropy of the system would increase.*

Indeed, in *any* localized or small-scale closed system in which the conversion of energy from one form to another involves loss of some of the energy to heat, the entropy of the system is increased to some degree. It is as though of all the energy present in such a system in all its various forms, the energy occurring in the form of heat forms a sort of pool or reservoir of essentially useless energy, in a form relatively incapable of doing work; and as quantities of energy in other forms are purposely or inadvertently converted into heat energy they are "lost" into this ever-increasing reservoir of relatively useless heat energy, so there is increasingly less and less energy left in the system in forms capable of doing work, and no effective "natural" way for this gathering quantity of heat energy in the system to be converted back into useful forms again. And as the heat energy (relatively disordered and useless) piles up, the entropy of the system steadily increases.

Well, we might ask, so what? There's plenty of energy around. Who

cares if the energy in one or another small closed system becomes increasingly disordered and useless? Is this something to worry about?

Many physicists of the mid-1800s thought it was, for they *extended* what they had observed in small closed systems out to what seemed to them a logical extreme: They began arguing that the same steady and inexorable increase in entropy occurring in such small closed systems must also be occurring *in the entire universe*. Indeed, they speculated that all the energy in the universe was gradually, bit by bit, irrevocably being converted into heat energy, that the entropy of the universe was thus steadily increasing, and that ultimately, in the far distant future, the entire universe would come to an end in a dismal sort of "heat death" with all the stars, planets, and everything else in it fried to a crisp and converted into heat energy!

To understand more clearly why such an apparently outlandish idea was seriously debated by physicists right up to the last decade or so, let's see how the increase in entropy in a closed system works, with its inevitable concomitant decrease in the amount of useful, work-capable energy, by means of a simple analogy. Imagine a very rich man with a vast quantity of money in his pocket—hundred-dollar bills, fifty-dollar bills, ten- and five-dollar bills, and one-dollar bills, as well as half dollars, quarters, dimes, nickels, and a few pennies. Then imagine this man going about his daily life trading money for goods, and then retrading the goods for money. Suppose also that the prices he pays for goods and the prices he receives in exchange for goods are frequently odd amounts—a bottle of perfume $10.18, a package of razor blades $0.99. Under these circumstances all sorts of conversions of money would occur. One-hundred-dollar bills would be broken into tens, twenties, and fifties. Half dollars would be broken into quarters and dimes, and—inevitably, because of the irregularity of prices—dimes and nickels would be converted into pennies.

In fact, in virtually every exchange a larger-denomination coin or bill would be broken down into a smaller one, and in virtually every exchange the man would end up with a few more pennies than he had before. We might say that over a period of time, he would find himself losing more and more of the larger-denomination bills and coins and accumulating heaps and piles of pennies. Now, suppose in this strange country that it was perfectly possible for one to gather up pennies and trade them for nickels, dimes, quarters, or dollars, but that everybody else had too many pennies, as it was and really didn't want any more. Thus it was always far more difficult, if not impossible, to trade pennies for dollars than it was to buy goods with the dollars and end up with a few more pennies.

Finally, suppose that in the entire country there was only one bank that was required by law to trade dollars for pennies, and that bank was only required to take ten dollars' worth of pennies from any one person on any one given day, and anyway the bank was located two thousand miles

away from where our rich man lived. The end result of such a system is obvious: Bit by bit the man would accumulate more and more of his money in the form of pennies which he couldn't use very well, and have less and less of it in the form of useful hundred-dollar bills, ten-dollar bills, half dollars, and quarters. We could even imagine that if something didn't happen presently to revise this badly misbalanced monetary system, not only our man but all the other merchants in the nation would eventually, bit by bit, end up with no useful form of currency whatever and all commerce would grind to a halt, quietly smothered in pennies.

Of course, in this analogy, the rich man, his country, and the country's monetary system were all a closed system—what happened there would not necessarily happen in another country on another planet. But physicists of the mid-1800s saw no reason why this principle of entropy increase—which seemed more and more to be a natural law—should not be *universalized* or extended to the entirety of the universe. Thus they wrestled with this puzzling notion that all the energy in the universe was gradually, bit by bit, being converted into comparatively useless heat. Surely there must be some way that the universe's "monetary system" could be revised!

One man who came up with an answer was James Clerk Maxwell, the brilliant student of Michael Faraday, but the answer he found was in the form of a clever paradox which simply seemed to indicate that no such "revision" could ever be hoped for. In a study of the dynamics of heat energy published in 1871, Maxwell postulated a cylindrical vessel much like a large tomato-juice can divided into two sections, A and B, by means of a rigid dividing plate with a hole in it. Then Maxwell imagined that a demon was standing guard by the hole in the separator, a demon with eyes so sharp that he could follow the motion of every molecule in each portion of the container and determine whether it was moving fast or slow. Maxwell's demon was then instructed to open or close the hole between section A and section B of the container in such a way that *only the slower molecules could pass from section A into section B and only the faster-moving molecules could cross from B to A* (see Fig. 12).

Presently the sorting activity of the demon would begin to show measurable results: More and more of the swifter molecules would become concentrated in section A of the container, while more and more of the slower ones would become concentrated in section B. Since the "temperature" of a gas is merely a measure of the average speed of its moving molecules, the temperature in section A would begin rising while the temperature in section B would begin falling. What Maxwell's demon would actually be doing, in opening and closing the hole between the two sections of the container in this discriminatory fashion (and without expending any work whatever, since he was a demon) would be to *reverse the natural flow of heat* into adjacent areas and make hot molecules gather in one section

and cold molecules gather in the other. Thus he would be creating a system in which the "order" of the heat energy present becomes greater and greater, and in which the entropy of the system steadily decreases.

What was wrong with Maxwell's demon? Why was it not possible for the entropy of such a system to decrease rather than increase—for the heat energy to seek a higher level of order rather than a lower level? The simplest answer, of course, would be to ask Maxwell to produce his demon—but unfortunately no such entity has ever been known to science, either then or now. Even aside from that, the bargain was just too good to be true. The sorting activity of Maxwell's demon would, in fact, have constituted a perpetual motion machine, because the flow of heat from the warmer region A of the vessel to the colder region B could be made to do mechanical work. This, after all, is what makes a steam engine do work.
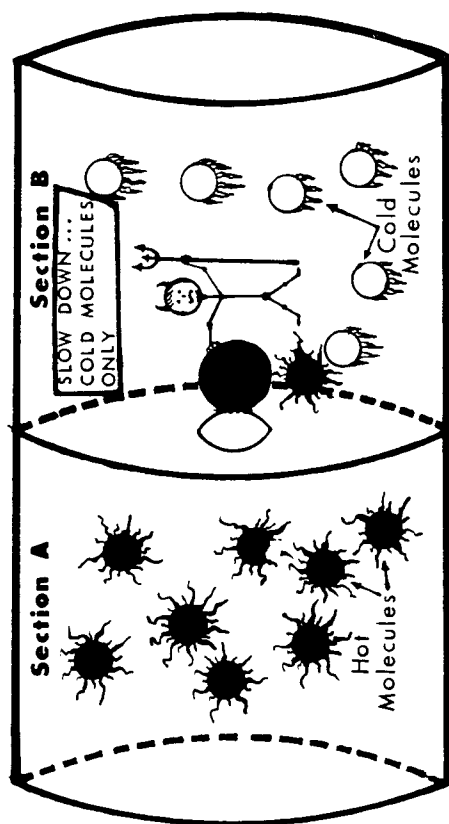

Fig. 12 Maxwell's demon, guarding the porthole to permit only fast, hot molecules to cross into Section A and only slow, cold molecules to enter Section B. Doubtless he became a demon for violating the Laws of Thermodynamics!

But the real reason that Maxwell's demon could never work, we know today, is not because such a device could not be constructed, but because even if it *could* be constructed with the aid of miniaturized integrated circuits, the demon would *still have to expend energy to find out the velocity of each molecule in order to do the sorting.* And the energy needed to do this and proceed with the sorting would turn out to be *exactly* the amount of energy needed to operate a heat engine to pump energy from one side of the vessel to the other! (We will see just *why* energy is needed to find out the velocity of each particle in a later chapter.)

Thus Maxwell's demon proved to be nothing but a fanciful fallacy. But even without a demon to guard the hole between section A and section B of the vessel, is it not possible that more and more of the hot molecules

might, *of their own accord,* speed through the hole into section A while more and more cold molecules, *of their own accord,* found their way through into section B, so that section A would still get hotter and hotter while section B got colder and colder?

Possible? Yes—there would be nothing to prevent any given molecule from crossing through the hole in either direction. But now we are talking not just about *possibility,* but about *probability* as well. Given such a container divided into two sections by a partition with a hole in it, it would be perfectly *possible* for all of the millions of faster gas molecules to move one by one through the hole into one portion, and for all the millions of slower, colder molecules to find their way one by one into the other part of the container, quite of their own accord. It *could* happen as a result of the random movement of the molecules, purely by chance. Note that we said it would be *possible.* But *probable?* No. The *probability* that any such thing should ever happen anywhere, even once, in all the history of the universe, is so infinitesimally small that it can as well be ignored. And if Maxwell's demon were on hand and able to sort molecules and open and shut the hole in the partition, it would be violating mathematical probability by making hot molecules flow to the hot side and cold molecules flow to the cold side *every time,* whereas the "natural" flow of heat energy from an area of organization to an area of disorganization is a matter of probability so high that the possibility of the opposite sometime coming to pass under some natural circumstances can simply be dismissed from consideration altogether.

We can see the distinction between *possibility and probability* with a simple experiment. Take a roll of 100 pennies, shake them in your hand, and then toss them freely on the rug. Since each one of the pennies spins freely in the air and may fall either heads up or tails up, there is a possibility that all 100 pennies will land heads up, without a single tail showing. The probability that this will occur, however, is extremely remote—so remote that we would be tempted to say that it "never" would happen—except that we know of no law of nature that says it *can't* happen.

The *probability* is that any time the pennies are so thrown the result will be within a few pennies one way or the other of a perfectly equal distribution, and this will be the case even if all the pennies in the roll have been stacked heads up to start with. A deviation of 10 per cent either way from a perfectly even distribution of heads and tails would be unusual. A deviation of 20 per cent either way would be remarkable, and a deviation of 30 per cent either way would be so extraordinary that it would be unlikely to occur a second time if you kept tossing the pennies in this fashion over and over again all year—although it would be just as *possible* for it to happen on the second throw as on the first.

Exactly the same situation obtains in the case of hot and cold gas molecules separating themselves out by means of their random motion

The Manifestations of Energy

energy in relation to other forms of energy became so convinced of the natural tendency of heat to move from an organized (hot-cold) system to a disorganized (uniformly lukewarm) system that they began to consider this pattern of behavior as a fundamental law of nature and described it in two simple rules which have come to be known as the *laws of thermo-dynamics*. Today both are considered basic laws of nature. The first law of thermodynamics is simply a restatement of the law of conservation of energy: *Energy is always conserved, and can never be destroyed.* (This implies, among other things, that no perpetual motion machine such as Maxwell's demon may be built.) The second law of thermodynamics states: *In any closed system there is a tendency for the individual units making up the system to change from a state of order into a state of disorder, so that the amount of information we have about the system becomes smaller as time goes on.* A simpler way of stating this law, providing we understand what is meant by "entropy," would be to say: *In any closed system the entropy must always either remain unchanged or increase.*

This second law of thermodynamics is really nothing more than a restatement of Lord Kelvin's principle that we quoted earlier: *"Heat cannot be transferred from a cold body to a warmer body without the aid of some outside source of energy."* But the fascinating thing about this second law of thermodynamics is that it is the first fundamental natural law we have encountered which depends upon probability rather than invariable behavior. If we wanted to be absolutely precise, we would have to rephrase the second law to say: "While it is not *impossible* for heat to move from a cold body to a warmer body without the aid of some outside source of energy, such an occurrence is so incredibly *improbable* that we can never reasonably expect it to happen."

Assuming that these laws of thermodynamics were really valid everywhere in the universe under all circumstances, not just in the small part of it they had been able to observe personally, those physicists of the mid-1800s became exceedingly gloomy about the likelihood of anything occurring in the universe to "change the monetary system"—to make it suddenly possible for the entropy of any closed system (including the entire universe as a closed system) to begin to increase again. Certainly an extensive survey of known examples of energy transformations within natural systems seemed to indicate that the entropy of any given system would almost invariably remain unchanged or would increase, with only a rare system occurring in nature in which entropy decreased even slightly. Actually, there *are* situations—situations, for example, involving the exchange of energy in the cells of living organisms, in which heat is converted back into other forms of energy, or moves from areas of low heat content to areas of higher heat content. But whenever this happens, even in the metabolism of living cells, it is *forced* to happen in the course of chains of one-way, irreversible chemi-

The Universe of Classical Physics

into opposite sides of a container: possible but highly improbable, with the improbability all the greater because there are billions and billions of gas molecules to take into consideration while there were only 100 pennies.

The study of the behavior or movement of heat from an area with a certain heat content to another area with slightly lower heat content (or vice versa) is known to physicists as *thermodynamics*, a term that seems carefully calculated to scare nonscientists away in a panic. All the term means, of course, is the study of the dynamics (i.e., of the movement and/or behavior) of heat or heat energy. In thermodynamics a situation in which a container containing only hot (that is, fast-moving) gas molecules is adjacent to and connected with another container containing only cold or slow-moving gas molecules is said to be an "ordered" or "organized" system simply because we know a great deal about the individual molecules in such a system. We know that most of the molecules on the hot side are going to be moving around swiftly while those on the cold side will, on the average, be moving more slowly, and that the probability that any given molecule in the system would be found to be moving swiftly would be far greater on the hot side than on the cold side. As the hot molecules from the one side intermingle and mix with the cold molecules on the other side, the heat differential between the two sides decreases—and so does the accuracy of our knowledge about any given molecule in the system. By the time equilibrium has been reached between the two sides, we know virtually nothing about any given molecule's movement—the probability of finding any given molecule moving faster or slower on either side would be precisely the same.

Thus we could equally well say that the entropy of a given system is a direct measurement of *how little we know about the individual molecules in the system*. When the system is highly organized, we know a great deal and the system has low entropy. If the molecules diffuse from side to side and the heat content of the two sides begins to equalize, the entropy of the system increases and by the time perfect equilibrium is reached, entropy has increased to its maximum (i.e., disorder or disorganization) of that system has increased to its maximum. *But then there is no way for the entropy of the system to decrease again without outside help.* The heat content in the ordered system with low entropy has been dissipated and diluted into a disordered or disorganized system with much higher entropy, and the process does not reverse itself naturally. When the opposite thing occurs, as when our open freezer is forced to become colder even when open to a warm room, the entropy of the system of cool freezer and warm room has decreased, but we had to expend a great deal of electrical energy and mechanical energy to bring this about. In fact, in any system in which a form of energy higher on the ladder than heat is converted or "lost" to heat energy, the entropy of the system increases.

As we have seen, physicists of the early 1800s who were studying heat

cal reactions which require the addition of significant amounts of new energy in order to proceed.

Such natural situations, moreover, are rare. For the most part, any systems in which heat is converted into other forms of energy show the fine hand of man at work. These are usually artificial man-made systems such as the household freezer we spoke of which we have ingeniously devised in order to *force* a flow of heat in an "unnatural" direction, with a resulting decrease in entropy, in order to achieve some particular predetermined advantage.

What is more, such "abnormal" systems will continue to operate only at great expense in outside energy input, and only as long as we force them to continue. In operating them we are, in effect, flying in the face of natural law, and though we may gain a temporary advantage it is usually costly. Scientists such as George Gamow have pointed out that if we could create a system in which entropy was easily and cheaply decreased we would in effect be creating a sort of perpetual motion machine. For example, if it were possible to utilize the natural heat of the ocean cheaply as a source of energy, it would be possible to operate a ship almost perpetually simply by drawing the warm sea water into its engine, converting the heat into mechanical energy to turn the screw, and tossing the resultant blocks of ice overboard. If this could be accomplished without using up more energy to convert the heat energy into mechanical energy than the mechanical energy we got out, our ship could continue to travel about scot free until the temperature of the ocean had been reduced to the freezing point of salt water all over the earth—which might mean virtually forever, considering the amount of water there is, the smallness of the ship, and the constant warming action of the seas by the sun.

But such a "perpetual motion machine of the second order" (that is, operating in violation of the second law of thermodynamics) could never be made to work simply because we would always have to use far more energy in some other form in order to convert the heat from the water into useful mechanical energy than we could ever get out in the form of mechanical energy to turn the ship's propeller; far from getting off scot free, we would do far better at far less cost to use more economical fuel in the first place. Maxwell's demon would represent another perpetual motion machine of the second order: The demon, so to speak, would have to be fed in order to keep him working at determining molecular velocities and separating fast molecules from slow molecules, and we would soon find that he had a voracious appetite!

But what do these laws of thermodynamics mean in the long run? If they were really universally valid anywhere under any circumstances, it would appear that in almost all natural systems in the universe there must be a constant dissipation of useful forms of energy into useless heat. The rare instances in which man succeeds by his gadgetry in reversing this process

temporarily by means of one device or another would not amount to a hill of beans in terms of the total amount of energy in the universe. Thus, it would seem inevitable that as time passed and more and more energy of all varieties had dissipated into heat, and as more and more matter in the stars and galaxies was consumed to create more energy, that the entire universe bit by bit would increase in entropy, growing steadily hotter and hotter. Indeed, this increase in the heat content of the universe would really be a function of time; and sooner or later the entire universe would contain nothing whatever but an enormous quantity of heat energy—no living creatures, no stars, no planets, no matter as such, nothing but energy all reduced to an enormous quantity of heat.

That was the dismal forecast for the future that physicists of the late nineteenth century and the early twentieth century were thinking of when they argued and debated about the "entropy increase and heat death of the universe." And as a subject for perpetual fretting, it would be hard to beat, although this gloomy fate was not expected to overtake the universe for another 500 billion years or so. In recent decades, however, modern cosmologists have come to pooh-pooh the whole concept of heat death of the universe, and maintain that it will never actually occur. The assumption that the laws of thermodynamics apply everywhere in the universe under all circumstances may not be entirely valid, they maintain—or at least there is evidence that the laws may not apply quite as they were originally understood. Cosmologists argue that entropy in our universe is not a quantity clearly enough defined under all circumstances for us to make broad generalizations about its increase or decrease throughout the universe—the entropy of a gravitational field, for example, is not defined. Nor do the laws of thermodynamics seem useful in explaining increase or decrease of entropy in an expanding universe, or in an oscillating universe, such as we will discuss in a later chapter. For the moment, the best we can say is that entropy increase is a clearly defined tendency at least in small, localized closed systems—systems here on earth, for example, or systems involving our solar system in its present stage of evolution—but that even our grandchildren need not worry about the heat death of the universe ever occurring unless they really want to.

Now consider that we have just produced a lengthy and rather vague verbal description of a very simple phenomenon. Even selecting our words with great care, we still do not succeed in presenting a *precise* description of

what happens as we move a loop of wire into, through, and out of a magnetic field. Certainly we have not even begun to describe precisely what is happening at any given instant during this experimental procedure. Of course, we can imagine this interaction between a loop of wire and a magnetic field as occurring through a series of tiny instants of time and plot what is happening at each such instant on a piece of graph paper. We could then find out from the graph more or less what was happening at any given instant we wanted. But unfortunately, even this laborious process would still not show us *precisely* what was happening at any given instant, because the interaction between the wire and the magnetic field did *not* occur as a series of tiny stepwise changes occurring instant after instant until the process was over. The changes that occurred were continuous, smooth, and unbroken.

But then, is there *any* way we could describe such a phenomenon with absolute precision? Indeed there is a way, and Maxwell used it. He described what was happening by using a form of mathematical language that had been expressly invented in order to describe continuous unbroken motion or action—a type of mathematical expression that is known as the "differential calculus."

This particular form of mathematical language is particularly fascinating because it was literally *invented*—made up out of whole cloth—at almost precisely the same time by Isaac Newton in England and Gottfried Wilhelm Leibnitz in Germany, working quite independently, in order to be able to describe a type of motion that could not be accurately described in any other way. Newton invented this form of mathematical expression for precisely the same reason that Maxwell needed it to describe Faraday's concept of unbroken changes arising from interaction of electromagnetic fields. Newton needed some way of describing in mathematical terms the continuous unbroken motion of physical objects; for example, the motion of an artillery shell fired from the mouth of a cannon and moving horizontally through a gravitational field. When he discovered that there was no mathematical language available for such description, he cooked up his own, and his differential calculus proved invaluable for describing the rate of change of any number of smoothly variable quantities.* Maxwell used the differential calculus to describe the rate of change of another variable quantity: the developing, cresting, changing of direction and then receding

* Interestingly enough, although Newton and Leibnitz invented the same differential calculus independently of one another, they used two entirely different sets of mathematical symbols and notations. At first, of course, Newton's notations were used in England and Leibnitz's in Germany, but later on at Cambridge two separate groups of mathematicians formed in strong opposition to each other, fighting bitterly about what notations to use. They ended up coming much closer to Leibnitz's notations (which are approximately those we use today) than to Newton's, which were much more complex and more difficult to follow. But this was essentially a quibble about what mathematical symbols to use; the basic method of the calculus that Leibnitz invented (as well as the basic application of it) was identical to Newton's.

of an electrical current in a wire that was moving through a magnetic field.

Maxwell's equations were a triumph in two ways. First, they demonstrated beyond any question that there were certain phenomena of nature in the universe which could be better described in the language of mathematics than in any other way—indeed, phenomena which could not be described *at all* except in the language of mathematics. Second, his equations demonstrated clearly that electromagnetic interactions, at least, could in fact be described by a set of mathematical equations based on the differential calculus, and that this procedure did a better job of describing the stresses and strains in this mysterious, invisible yet apparently elastic medium known only as a "field of force" than anything else. Maxwell's equations made it possible to determine the strength of electric and magnetic force fields during any given interaction.

But even more significant and more amazing, those same equations described perfectly the *shape of the waves* that were known to be formed by a vibrating violin string, or by a sound wave traveling through air. In fact, Maxwell's equations indicated that comparable waves ought also to be formed any time an electric field of force interacted with a magnetic field of force. They indicated that the potential energy of an electromagnetic field (that is, energy stored in such a field) should be capable of conversion into kinetic energy in the form of high-velocity waves and then be reconvertible into potential energy stored in the electromagnetic field again whenever a loop of conducting wire was moved through a magnetic field.

In short, his equations indicated that an interaction between an electric field of force and a magnetic field of force ought to create an oscillating shift of energy from potential energy to kinetic energy and back to potential energy again—a shift of energy which behaves in a regular repetitive manner virtually identical to the behavior of a pendulum or any other vibrating or oscillating system.

We do not intend to go into the mathematical expressions that Maxwell worked out; there is no point to our doing so here. The mathematical analysis of the results of this kind of interaction in an electromagnetic field can be found in any textbook of physics by any mathematically inclined reader who wants to look them up. From our point of view, it is enough to recognize that Maxwell, by means of his equations, predicted unequivocally that the interaction of electrical and magnetic fields ought to produce "electromagnetic waves" that would radiate out into space any time an interaction between such fields occurred. In other words, Maxwell predicted that electromagnetic forces not only interacted at their source, but also inevitably emitted energy in the form of electromagnetic waves any time such an interaction took place. What was more, those electromagnetic waves, according to Maxwell's calculations, had to travel from one place to another at the same staggering speed that light traveled from one place to another, and that like light waves, these electromagnetic waves could

travel freely not only through air and water but through totally empty space.

When we stop to consider the implications of this notion, we can begin to see what a truly revolutionary idea it was. For the first time in history, a scientist was using theoretical mathematical calculations to predict that something existed in the universe which no one had ever detected, or even thought of before. As we might expect, Maxwell's equations were met with skepticism if not flat disbelief. Physicists all over Europe said, in effect:

"These equations are very nice, and they suggest that under certain circumstances something will happen that we've never heard of before—but show us. Where is the experimental evidence? Where is the proof?" Maxwell's equations stirred a furor, even in the minds of those investigators who had deeply admired the experimental work of Faraday, and had been working to duplicate it in their own laboratories. They did not realize that James Clerk Maxwell had in fact pioneered one of the mightiest and most revolutionary concepts of modern physics.

It is not hard to see why Maxwell's equations made other scientists uneasy. He was saying, in effect, that by pursuing mathematical calculations to their logical conclusions a scientist might predict a phenomenon, or a series of events, or some other kind of occurrence in the physical world before any such phenomenon, series of events, or occurrences had ever been observed under experimental conditions. In the world of modern physics this is not merely an accepted idea which manifests itself on rare occasions; it is one of the most well accepted and basic concepts that modern physicists count upon: that mathematics can predict reality, that mathematics indeed is the guide that shows experimental physicists where to experiment; in fact that if mathematics predicts one thing and experiment suggests another, it is wiser to accept the predictions of mathematics than the experimental results in the laboratory.

Today this is a commonplace and accepted principle, but for the physicists of Maxwell's day, it was a most uneasy notion. Not that those men could find fault with Maxwell's mathematics; he was far too good a mathematician for that. But they could indeed question sharply whether Maxwell's equations and the predictions that they implied had any real *meaning* in terms of observable phenomena in the physical world. If, as Maxwell's equations predicted, there really were "electromagnetic waves" which were created and sent moving out through space every time an electric field interacted with a magnetic field then, they said, *it ought to be possible deliberately to produce such "electromagnetic waves" experimentally in the laboratory.* They also insisted that it ought to be possible to *detect* such waves, and that when detected they ought to be found to behave precisely in the fashion that Maxwell's equations predicted they would behave.

As with most complaints, scientific or otherwise, it proved far more difficult to produce the experimental proof than it was to make the prediction. In this case, more than twenty years elapsed before a German physicist named Heinrich Hertz succeeded in producing a beam of electromagnetic waves by driving electrical charges rapidly back and forth through a wire connected to two electrically charged conductors bearing opposite charges. In doing so, in 1888, he showed that any vibrating or oscillating electrical charge sent out a train of electromagnetic waves which did indeed rush off into space in all directions with an enormous velocity.

This was very strange, something which never before had been accomplished or observed. Even more strange was the discovery that the velocity of these electromagnetic waves was *precisely* the same as the velocity of light, and the fact that these waves could move indefinitely through empty space *precisely* as light traveled through empty space. The discovery of Heinrich Hertz did not go unnoticed very long; in the year 1896 an Italian engineer named Guglielmo Marconi discovered that these waves arising from oscillating electric charges could be transmitted from one place and received or picked up at a great distance, and at one fell swoop Marconi laid the whole basis for modern radio and wireless telegraph communication systems.

The discovery that electromagnetic waves could be produced was not an isolated scientific achievement; it dovetailed neatly with the studies of wave phenomena of all sorts, and with the investigation of the nature of light. Like the key piece in an immense jigsaw puzzle, this discovery suddenly fitted into place and made sense of a multitude of other pieces which fell into place bit by bit with increasing rapidity. The phenomenon of light, which was so long considered to be a completely unique phenomenon of the universe, began to appear more and more like a small isolated fragment of a much greater picture. It became more and more clear that light waves were merely a small and perhaps even relatively insignificant branch of a much larger family, so to speak. It was already known that in addition to visible light in the rainbow spectrum, there were also two varieties of "invisible light," one with a longer wavelength (infrared) than visible light and one with a shorter wavelength (ultraviolet). The electromagnetic waves which Hertz produced experimentally had a much longer wavelength even than infrared radiation, but also traveled through space at the speed of light. Much later, in the early 1900s, yet another kind of radiation or stream of electromagnetic waves was produced by bombarding a target of tungsten with a beam of electrically charged particles driven with enormous energy. These waves had wavelengths that were far shorter than the already identified "short" ultraviolet waves, and for reasons that we will explore later, became known as X-rays.

In fact, it soon became obvious to physicists that a wide band or "spectrum" of electromagnetic waves existed, ranging from exceedingly short wavelengths to extremely long wavelengths, and that these waves were

The Baffling Enigma of Light

invariably produced by oscillations or vibrations of electrically charged objects or particles in electromagnetic fields. Only a very narrow band of this broad spectrum of electromagnetic waves was made up of waves of just the right wavelength that the human eye could detect them as visible light—but the implication of the idea was clear. Visible light itself also consisted of electromagnetic waves, and visible light, like all other electromagnetic waves, always originated from the movement of charged particles in an electromagnetic field. Later, it was found that light waves had their origin in the movement of charged elementary particles moving in the interior of atoms themselves. But even before this was recognized, physicists at last felt that they had encountered the beginning of an answer to the ancient questions of what light really is and where it really comes from.

The Demon in the Aether
The Story of James Clerk Maxwell
Martin Goldman, 1983
Paul Harris Publishing
Edinburgh, pages 122,123

The status and significance of his distribution law may not even have been clear to Maxwell himself at the time. One of the problems he considered in the first draft of the paper was the dependence of temperature on height in a vertical column of gas. As he frankly admitted in his final version of the paper, his first attempt at a solution to this problem went wrong because of a fairly straightforward mathematical error, and led to a solution where the temperature dropped off so rapidly with height that the column became unstable: perpetual currents of air would result. Maxwell wrote a private letter to Thomson about this saying he was worried. Thomson in his referee's report for the Royal Society recalled that he too had been worried—as well he might, since the gas column appeared to break both the 1st and 2nd laws of thermodynamics which Thomson had done so much to establish.

Maxwell found a mistake in his calculation and produced an improved solution where the temperature now increased with height. This was at least mechanically stable. Further reflection, however, showed that this too broke the 2nd law, and further checking showed that this time he had made a simple arithmetical error. The final solution was that the temperature is independent of the gravity and the 2nd law stayed intact.

A number of rather subtle points emerged from this little academic comedy. Firstly Maxwell submitted, yet Thomson did not immediately and categorically veto, a paper defying the 2nd law of thermodynamics. No paper would be so leniently treated today. On the other hand, when the paper was finally corrected, compliance with the 2nd law was seen to depend rather directly on the specific mathematical properties of Maxwell's distribution formula. Clausius' distribution law, for example, would inevitably defy the 2nd law. The full implication of the connection became clear only with the invention of the Maxwell demon, a delightful beast who has tormented theoretical physicists ever since.

He first appeared in a letter to Tait, on 11 December 1867:

> Now conceive a finite being who knows the paths and velocities of all the molecules by simple inspection but who can do no work except to open and close a hole in the diaphragm by means of a slide without mass...[24]

Maxwell proceeded theoretically to set up a container with a diaphragm in the middle separating a hot gas on one side from a cold gas on the other. But in the cold gas, by Maxwell's formula there should still be *some* fast molecules, and in the hot gas, *some* slow ones. Maxwell's finite being, or demon as he became universally known, works his slide so that the fast molecules from the cold side pass to the hot side, and slow molecules from the hot side pass the other way:

> ... that is the hot system has got hotter and the cold colder and yet no work has been done, only the intelligence of a very observant and neat fingered being has been employed.

Thus, Maxwell continues, if we were sufficiently nimble fingered we could break the 2nd law 'Only we can't, not being clever enough'.*

This notion intrigued Tait who promptly referred it on to Thomson for a higher opinion. Both T and T' were convinced. The demon has led a checkered existence since then, and has in large part led to the current development of information theory. The generally held opinion now is that the demon cannot work; to see the fast and slow molecules arriving he would have to receive light from them, and, by the precepts of quantum mechanics, bouncing a photon of light off a molecule alters its velocity, so the demon could no longer tell if it was fast or slow.

But what the demon did show was that the 2nd law is actually a statistical law.

> The second law of thermodynamics has the same degree of truth as the statement that if you throw a tumblerful of water into the sea, you cannot get the same tumblerful of water out again.[26]

* The nearest thing to a demon is the remarkable trickshot at pool played by Buster Keaton in the film *Sherlock Junior*. He hits the cue ball into a seemingly random pack, pocketing them all but one. It was not faked, but it did take Keaton whose grasp of mechanics must have rivalled Newton's a whole fifteen minutes to prearrange the balls on their proper spots so they would all travel precisely to their pockets.[25]

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The Story of Mechanics
by A. Russell Bond
P.F. Collier & Son 1948

THE GIFFARD INJECTOR

As steam is used from a boiler the water is slowly
exhausted and it must be replenished with a fresh supply.
In early days of the steam engine, water was pumped
in against the boiler pressure by the use of powerful
pumps, but in 1858 a man named Giffard invented a
most ingenious apparatus by which steam of the boiler
was used to force water in directly against its own pres-
sure. This seems like lifting oneself by one's boot straps.
When the injector was first invented it seemed so impos-
sible for it to work that engineers would not accept it
until it had repeatedly demonstrated its operativeness.
Even after it was accepted and in common use its myste-
rious operation was a subject of discussion for years. A
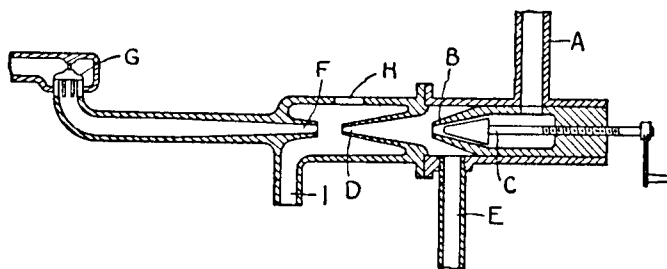
FIG. 47.—INJECTOR FOR INTRODUCING WATER INTO A
STEAM BOILER

sectional view of a Giffard injector is shown in Figure 47.
Steam from the boiler comes down the tube A and passes
out in a jet from the nozzle B. A needle valve C may
be moved into the nozzle to reduce or shut off the jet
of steam. The jet enters a conical chamber D which has
a tube E that runs down into the water reservoir. The
steam jet blows the air out of chamber D, producing
a partial vacuum which draws water up the tube E and
into the chamber D. When the water reaches the steam
jet it is driven out of the chamber across a short open
space into a slightly diverging tube or receiving cone F
and through a check valve G into the boiler. At H there
is a glass window through which the action of the water
jet as it rushes into the receiving tube may be watched.
I is an overflow pipe leading back to the reservoir. When
the steam flows into the cone B it gathers momentum
and issues from the nozzle in a jet of high velocity. On
striking the water it combines with the water and con-
denses, but at the same time it imparts its momentum
to the water so that the water is given more than enough
momentum to drive it into the boiler against the pressure
in the boiler.

The Story of Mechanics
by A. Russell Bond

SETTING KITCHEN FAUCETS TO WORK

The ancients used flowing streams not so much for power purposes as to lift water to a higher level so that it would flow into their irrigating ditches. Nowadays, electricity, steam, or air is used for elevating water, but we have a very ingenious machine which makes the stream lift a part of itself. This machine is very different in principle from the old Egyptian *noria*. It depends upon the kinetic energy of water in motion. You cannot push a nail into a piece of wood with a hammer but you can easily drive it in by striking it with the hammer. As the hammer is swung it acquires what we term kinetic energy or energy of motion.

It is not generally realized that water in motion also acquires kinetic energy. Whenever a faucet is turned off very quickly, there is a hammering sound, due to the fact that the moving water in the water pipe is brought to an abrupt stop. This puts a severe strain on the piping. A great deal of trouble was experienced from this source in the early days of plumbing. At a hospital in Bristol, England, there was a lead pipe leading from a cistern in one of the upper stories to the kitchen. Every time the faucets were turned off abruptly the momentum of the water caused the lead pipe to expand, and every now and then the pipe was burst. In order to relieve the situation, a plumber connected a pipe to the faucet and carried it up the side of the building to the level of the cistern. His idea was that whenever the water was turned off suddenly it would have a vent leading up to the level of the water reservoir. Much to his surprise, the water issued from the pipe in a jet of considerable height. To prevent the escape of the water, he extended the pipe considerably, and still a jet of water would issue from it. Eventually the relief pipe was carried up twice the height of the cistern and even then the water would squirt out occasionally when the faucets in the kitchen were turned off very suddenly. Then the idea was conceived of placing a reservoir on one of the upper floors of the hospital and letting the jet of water fill this reservoir. Every time the faucet was operated in the kitchen a certain amount of water flowed into the new cistern, and in this way it was kept supplied with enough water to furnish that which was required for the upper floors of the hospital.

It is on this principle that the hydraulic ram operates (Figure 33). Water from a stream is made to flow down a pipe, and as it gains velocity a check valve suddenly stops the flow, which produces enough pressure to force open a valve in an air chamber and let some of the water enter the chamber. As soon as the pressure is relieved the check valve opens and the valve into the chamber closes automatically until a moment later the stream of water has gained sufficient velocity to repeat the performance. Thus an intermittent jet of water is forced into the air chamber and thence through a pipe to a reservoir. The height to which the water will rise depends entirely upon the velocity of the water flowing through the system. The air chamber is necessary to cushion the action of the hydraulic ram and provide a fairly steady pressure upon the water that flows up through the vent pipe. The check valve is entirely automatic. It is held open against the pressure of the water by a spring or a weight, but when the water is in motion it is dragged shut, only to spring open again when the pressure is reduced by the escape of the water into the air chamber.

DIAPHRAGM

FIG. 34.—THE GYRATING WATER METER

FIG. 33.—SECTIONAL VIEW OF A WATER RAM

The Engineer, April 8, 1960, page 608

Hydraulic Ram as a Suction Pump

By N. G. CALVERT, B.Eng., Ph.D., A.M.I.Mech.E.*

EYTELWEIN (1803) in his classic work on the Hydraulic Ram[1] proposed a modification (Fig. 1) in order that the ram could be used as a suction instead of a forcing device.

In this proposal water was meant to flow from an upper level A to an intermediate level B. An impulse valve E was fitted at the
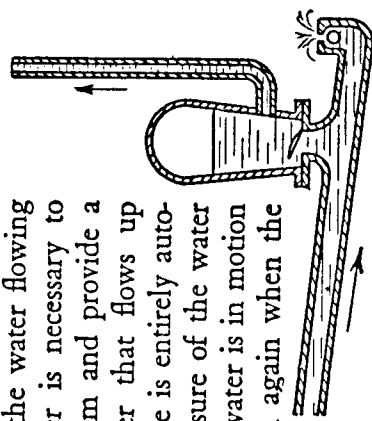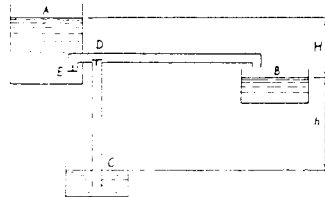

Fig. 1

entrance to a long drive pipe. When sufficient velocity was attained in this drive pipe, the hydro-dynamic drag on the impulse valve was to cause this valve to close. The inertia of the column was then meant to bring about a reduction in pressure at the point D which was to be sufficient to open the suction valve and set up a flow from the lower level C to the intermediate level B. The author has no evidence that Eytelwein, or anyone else, has hitherto attempted to construct such a device although the same effect has been achieved in a different way, in the "clean water" type of ram.

Recently the author constructed a suction ram of the kind suggested by Eytelwein. The

* Department of Mechanical Engineering, The University of Liverpool

first attempt was based on ½in diameter pipe and both suction and supply heads were about 2ft. After some adjustments this ram was made to work but it was unstable in operation and its capacity and efficiency were very low, the latter figure being less than 1·5 per cent. It was observed that the device always stalled with the impulse valve closed. This observation led ultimately to the construction shown in Fig. 2. The essential modification to
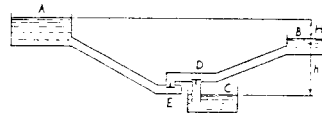

Fig. 2

Eytelwein's suggestion is the addition of a pipe AE between the pipe entrance and the impulse valve. The function of this pipe is to provide the negative surge necessary to re-open the impulse valve and so bring about stable working. A second modification found to be desirable was to shorten the suction pipe by lowering the valve box from the intermediate level B to the lower level C. In this form the device becomes a workable machine.

An experimental model based on a drive pipe (D—B) 1¼in diameter by 20ft long has been tested on supply heads varying from 2ft to 16ft with suction heads varying from 1ft to 14ft.

A typical set of experimental results are shown in Fig. 3. These are characteristic curves for a constant supply head of 4ft with

suction head plotted as the independent variable.

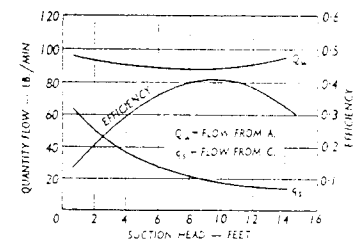The maximum suction capacity which has been observed in other experiments is

Fig. 3

76 lb min with an efficiency of 0·35 ($H = 10$ft, $h = 2$ft) and the maximum efficiency which has been observed is 0·7 with a delivery of 10 lb/min ($H = 2·5$ft, $h = 15$ft).

For stable working the length of the pipe DB is of some significance and it has an optimum value. This is controlled mainly by the beat frequency of the part of the plant AE considered as a hydraulic ram working under a head H. This in turn is controlled by the length of the pipe and the closing velocity of the valves (Calvert (1957)[2] and (1958)[3]). The adjustments are not critical and stable working continues over a wide range of suction and supply conditions. The device is self priming and can handle a mixture of air and water.

Possible applications might include the drainage of low lying land into an embanked river, the emptying of canal locks, turbine pits or riverside excavations during construction and repair and the use of a low head water supply for cellar drainage.

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Albert G. Bodine, Jr., Partial List of U.S. Patents
These inventions use acoustic power to pump water, drill rock, and other applications. Apparently, Bodine took up where Bellocq and Constantinesco left off.

2,350,212	5-30-44	2,796,735	6-25-57	3,295,837	1-3-67
2,355,618	8-15-44	2,854,816	10-7-58	3,299,722	1-24-67
2,444,912	7-13-48	2,942,849	6-28-60	3,303,782	2-14-67
2,480,540	8-30-49	2,953,095	9-20-60	3,307,278	3-7-67
2,480,626	8-30-49	2,960,314	11-15-60	3,308,671	3-14-67
2,543,758	3-6-51	2,960,317	11-15-60	3,402,612	9-24-68
2,546,965	4-3-51	3,096,833	7-9-63	3,536,001	10-27-70
2,546,966	4-3-51	3,111,931	11-26-63	3,633,877	1-11-72
2,553,541	5-22-51	3,076,544	2-5-63	3,684,037	8-15-72
2,553,542	5-22-51	3,102,482	9-3-63	3,740,028	6-19-73
2,553,543	5-22-51	3,153,530	10-20-64	3,805,514	4-23-74
2,554,005	5-22-51	3,163,240	12-29-64	3,837,239	9-24-74
2,572,977	10-30-51	3,123,043	3-3-64	4,023,628	5-17-77
2,581,902	1-8-52	3,143,970	8-11-64		
2,672,322	3-16-54	3,152,549	10-13-64		
2,702,559	2-22-55	3,191,537	6-29-65		
2,713,472	7-19-55	3,191,911	6-29-65		
2,731,795	1-24-56	3,217,551	11-16-65		
2,796,734	6-25-57	3,277,970	10-11-66		
		3,229,961	1-18-66		

New Pump Beats Natural Laws in Raising Water
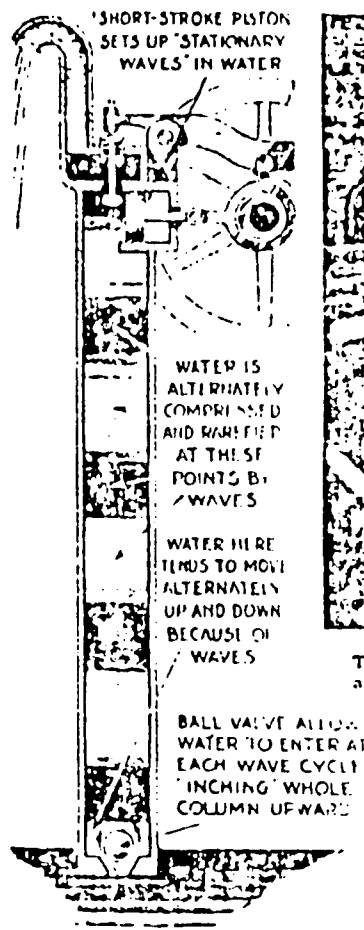
Close-up of the wonder-working pump that draws water from any depth by utilizing compression waves, as is shown in the diagram at the right

'SHORT-STROKE PISTON SETS UP 'STATIONARY WAVES' IN WATER

WATER IS ALTERNATELY COMPRESSED AND RAREFIED AT THESE POINTS BY WAVES

WATER HERE TENDS TO MOVE ALTERNATELY UP AND DOWN BECAUSE OF WAVES

BALL VALVE ALLOWS WATER TO ENTER AT EACH WAVE CYCLE 'INCHING' WHOLE COLUMN UPWARD

Toribio Bellocq, Argentine inventor of the wave pump assembling apparatus he used to get United States patent

FOLLOWING the example of the United States Patent Office, eighteen countries have issued patents to an Argentinian inventor upon an amazing pump that seems to violate natural laws. By creating waves in a pipeful of water, it makes the liquid run uphill.

When the inventor, Toribio Bellocq, applied for a United States patent on a pump to be mounted at the top of a well and to draw water up from almost unlimited depths, officials pointed out that his device apparently would have to defy the law of gravitation. Every high school student knows that by no effort can a pump *suck* water higher than approximately thirty-three feet. This is the limit at which the weight of an imprisoned column of water balances the atmospheric pressure outside. To force water higher from its source, authorities have always agreed that it must be *pushed* from below. Therefore Bellocq's "wave pump" seemed in a class with perpetual motion machines, which are not patentable because they are impossible.

Bellocq built one of his pumps, installed it atop a Washington, D. C., office building, and invited officials to inspect it. They saw it draw a steady stream of water up a pipe eighty feet high. Not until they dropped weights down the pipe and found no unseen machinery did they believe their own eyes. Then they acknowledged that Bellocq had chanced upon an entirely new mechanical principle and issued his patent.

So extraordinary is the operation of the new wave pump that even Bellocq admits he is not certain of its principle, and leaves to scientists the verification of his own explanation.

In Bellocq's pump a piston vibrates rapidly with an extremely short stroke. It deals hammerlike blows to a column of water in a pipe. His theory is that when the frequency of the blows is properly timed for the length of the pipe, a set of "stationary waves" is set up.

Suppose the pipe's bottom to be closed: then layers are formed where the water is alternately rarefied and compressed without moving. Midway between these and at the bottom are regions where water rushes alternately up and down because of the waves.

When a one-way ball valve is added at the bottom, water enters from outside at one point in each wave cycle, to replace water moving upward from the bottom of the pipe. Once inside, it cannot back out. Every influx of water "inches" the whole column upward, without interfering with the waves that travel through it. A valve at the outlet, while not essential, improves the efficiency.

Solar Water Pump

Device that works much like a steam engine, about one hundred years old in principle, demonstrated. Alternate vaporization and condensation of water provide pumping action.

▶ AN ENGINE powered by solar heat is now practical, the Conference on Solar Energy in Tucson, Ariz., was assured. It will be used for pumping water and should help make the dry and arid lands of the world more fruitful.

Demonstrated by Calvin D. McCracken of Jet-Heet, Inc., Englewood, N.J., the new Thermopump pumps water by a device that is much like a steam engine, but without piston or crankshaft. The principle is about a hundred years old, but has been applied only in the last two years.

Alternate vaporization and condensation of water between two check valves provide the pumping action, which recycles automatically. An air cushion is used to give an even flow. Heat storage will be designed and installed to continue the water flow during cloudy days and at night.

A working model of small size, powered by the rays of an electric lamp representing the sun, was demonstrated at the meeting. Mr. McCracken said flows of several hundred gallons per minute and heads of 1,000 feet are within the pump's reach.

For free information on availability of plans for building a Stirling ram pump, send SASE to: ABCO, PO Box 306, Seminary, MS 39479.
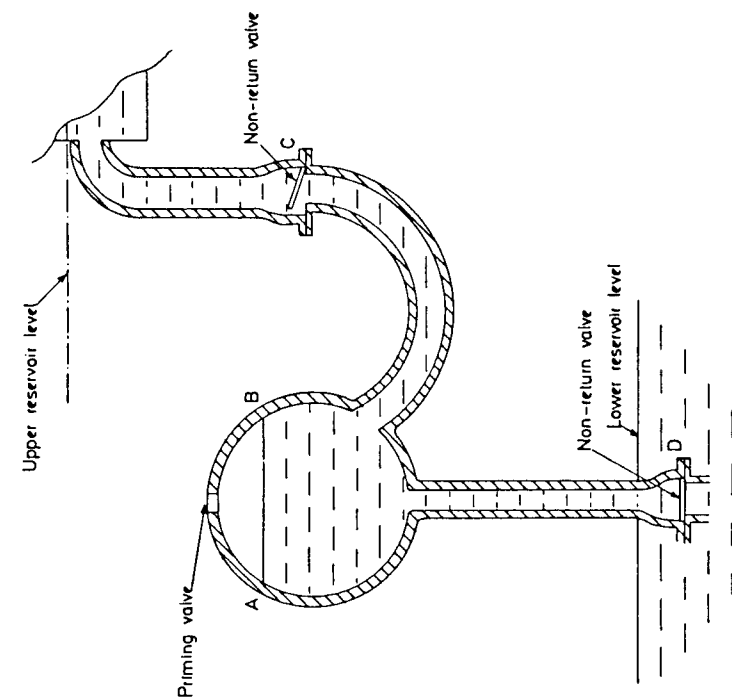
The University of Florida has also developed a very simple solar pump in which the only moving parts are two non-return valves (5). A boiler is connected by a U-tube to a vessel containing non-return valves at inlet and outlet. The inlet valve section is connected to the water which is to be pumped. The water in the boiler is heated and turns into steam, forcing water through the outlet valve from the vessel. When the steam reaches the bottom of the U-tube, it passes rapidly into the vessel and condenses, causing the inlet valve to open as a vacuum is formed. This system is a modern version of Belidor's Solar Pump, illustrated in Fig. 1.1. Another version has been developed in England by the AERE Harwell (6) and has a very simple closed cycle hot air cylinder instead of the boiler used by the University of Florida. A variant of the basic system, the 'Fluidyne 3' pump, is shown in Fig. 5.2. One end of the U-tube is heated and the resulting change in air pressure causes the water in the output column to oscillate, forcing water through the outlet valve and drawing fresh water into the system through the inlet valve. As long as the heat is applied, the pump will continue to oscillate at its resonant natural frequency. A solar pump
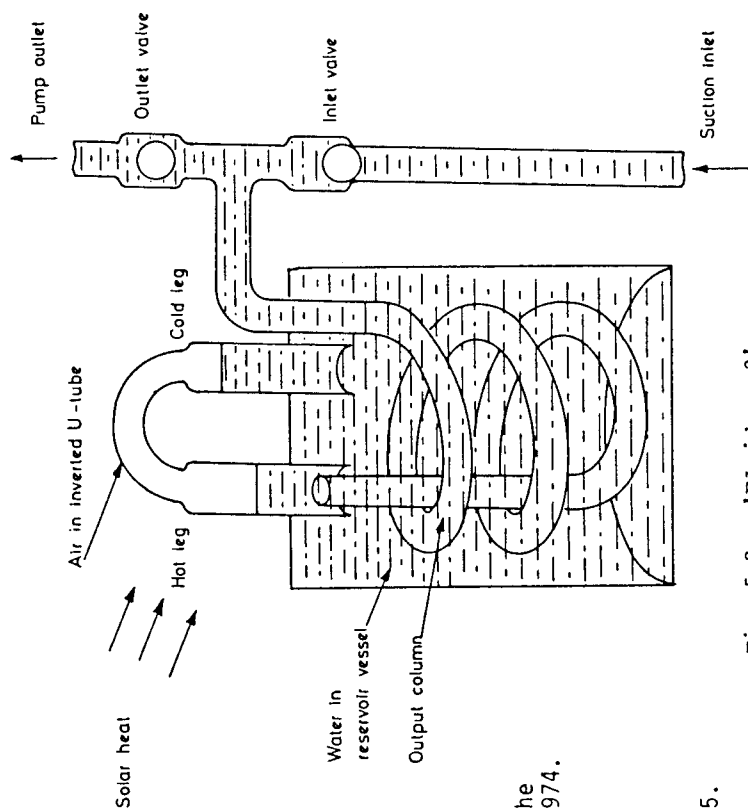
Fig. 5.2. 'Fluidyne 3' pump

developed in India (7) uses pentane vapour generated under pressure in a flat plate solar collector as the power source. Both an air-cooled and a water-cooled version are being studied.

Fig. 1.1. Belidor's Solar Pump

The pump is primed by filling the spherical dome to the level AB. During the day solar radiation heats the dome, causing the air to expand and force the water through the non-return valve C to reach the upper reservoir. On cooling, either artificially or at night, the internal air pressure falls below atmospheric, drawing water into the pump from the lower reservoir through the non-return valve D.

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(7) Rao, D.P. and Rao, K.S., Solar water pump for lift irrigation, ISES Congress, Los Angeles, Extended Abstracts, Paper 13/12, July 1975.

Sun Power by J.C. McVeigh
Pergamon Press 1977

"The Fluidyne Heat Engine", C. West, July 1974
Paper 5 in ISES Conference on Solar Energy Utilisation

Introduction

The Fluidyne is a heat engine which has no solid moving parts, no crankshaft or other rotating members, and is of extremely simple construction. The machine operates on a Stirling cycle and the mechanical output is in the form of a pulsating pressure or liquid flow which is well suited to pumping applications. A wide variety of heat sources can be used. A number of variations to the basic principle are possible, some of which are described below. The basic theory of operation has been worked out, but a number of important areas remain to be investigated. It has, however, proved possible with the present state of knowledge to design a number of working engines.

The Stirling Cycle

In the Stirling cycle heat engine, a quantity of gas is cycled between a hot and a cold cavity by varying the cavity volumes. The resulting gas temperature changes cause cyclic pressure variations which can be used to perform mechanical work. The efficiency can be improved if the connection between the hot and the cold cavities is through a regenerator which absorbs heat from the gas as it flows towards the cold cavity and replaces this heat when the gas returns. (1)

The basic problems in constructing a Stirling engine are firstly to achieve a cyclic volume variation in each of the two cavities, and secondly to ensure that the correct phasing is maintained - the hot volume change should be between 0 and 180° ahead of the cold volume.

The volume change has been realised by a variety of piston and cylinder arrangements (2) by means of bellows (3) and diaphragms (3). Crankshafts are normally used to achieve the desired phasing and to provide a power take off, although a hydraulic linkage has also been considered (4) which, however, still depends on the rotary motion obtained from the crankshaft.

The report describes an engine in which both the volume change and the phasing can be achieved hydraulically. In at least two configurations the only moving parts are liquid and no rotary motion is involved.

The Basic Fluidyne

The basic machine is outlined in Fig.1. As the liquid column in the left hand U tube oscillates, gas is displaced between the hot and the cold cavities formed in the spaces above the liquid, flowing through the regenerator. As the right hand liquid column oscillates the total volume of the gas is altered. If the hot cavity volume change leads the cold cavity by less than 180° the pressure change has a component in phase with

the velocity of the output column which can be used to overcome viscous friction in the output tube and to do external work. The problem is to maintain the amplitude and phase of the liquid in the displacer tube against viscous losses. Three methods of returning some of the available output power to the displacer have been tested and the engines are classified according to the method of achieving this feed-back. In general the displacer and output are two mechanically resonant circuits and must be correctly tuned for satisfactory operation.

1 MECHANICAL FEED-BACK

This is conceptually the simplest method, although because it involves a moving part the full advantages of the liquid piston scheme are not realised. The basic arrangement is shown in Fig.2. The whole engine is pivoted so that it can swing in the plane of the paper about point **A**. As the output liquid column oscillates, so the centre of gravity moves and the entire machine rocks against a restoring force provided by the spring S. This rocking serves to maintain the oscillation of the displacer liquid.

An experimental engine operating on this system has been built and successfully run. The displacer liquid was water and the output liquid mercury. The swept volume per cavity was approximately 3 cc and the operating frequency was 1 cps. The temperature difference approximately $60^{\circ}C$. Although deliberately designed so that most of the available power output was absorbed by viscous losses in the mercury there was a small excess of power which was used to drive a simple valveless water pump.

2 Pressure Feed-back

In this system the two cold cavity volumes (displacer and output) are combined. See Fig.3. Combining the cold cavities has the secondary advantage that the compression ratio can be increased since the unswept volume can be reduced. The cold cavity column is longer than the hot so that it has a lower resonant frequency, and the operating frequency lies between the resonance of the two columns. The time dependent force on the columns is the difference between the gas pressure P_e and the pressure in the container P_c.

The liquid velocity in the hot column will lead this pressure difference and that in the cold column will lag behind the pressure difference. By careful choice of the tube lengths and diameter, the phasing between the two columns may be brought to the desired value.

This feed-back technique has been proved by constructing a 1 cc engine operating at 1.7 cps and using water throughout. This machine consists only of glass tubing, water and air.

3 Jet Stream Feed-back

The two cold cavities are again combined, Fig.4. The
liquid streaming into the displacer U tube from the
output tube feeds energy into the displacer liquid
in the manner of a water jet pump.

This technique (a form of which was first suggested
by Cooke-Yarborough) together with the pressure feed-back,
enjoys the advantage that a machine can be constructed
which has no solid moving parts.

Experimental Results   A number of smaller engines with swept volumes of a few
cc's were built to test the three feed-back methods
described above. With these models, it was found that
the jet stream feedback system was the most flexible
and the least sensitive to leading or to mistuning of
the machine. Experiments with some small pumps using
simple ball valves had shown that the Fluidyne was
well suited to pumping applications. These devices
were operated from a variety of heat sources - infra
red, hot air and electrical resistance heaters.

The experience gained from these models was incorporated
in a larger water filled machine predicted to have
gallon per minute capability. One form of this
is shown in Fig.5. The energy source was a coil of heat-
ing cable around the hot cavity, itself surrounded by
glass fibre insulation. The valve A is used to fill
the machine with the required volume of working
fluid (which in these experiments was air). Water
for the cooling jacket could be taken either from the
pumping line or from a separate supply - both methods
were successfully tried. The engine was constructed
from brass and copper pipe fittings. This was
convenient, but, of course, the high thermal conductivity
of these materials leads to an unnecessarily large
heat leakage along the displacer tube. It is possible
that ceramic or plastic materials would be more
suitable, both on the grounds of thermal conductivity
and of the cost. 1 inch aircraft fuel line valves were
used in the pumping systems.

A number of experiments were carried out with this
machine and, in particular, the pumping rate was
measured as a function of pumping head and input
power. The results of one such series of experiments
are shown in Fig.6. With an input power of 250 watts
(e) the pumping rate with a small head is 1.35 gallons per
minute falling to 1.05 gallons per minute at a head of
3 feet. In this range the efficiency (defined as the
ratio of potential energy received by the pumped water
to the electrical input power) rises steadily to 0.35%.
Although this figure may seem rather low it should be
borne in mind that much of the input heat is lost down the
copper tubing direct into the cooling water. In all
cases the operating frequency was approximately 1 Hz.

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With the input power raised to 530 watts, 1.4 gallons
per minute were pumped through a head of 5'3". This
corresponds to a pumped power of 1.7 watts and an
efficiency of 0.32%.

Discussion

The realisation of a Stirling engine using liquid
pistons to achieve the required volume changes, and
mechanically tuned liquid columns to ensure the
correct phasing, is shown to be theoretically and
practically feasible. The resulting machines become,
with the addition of inlet and outlet valves,
simple heat-powered pumps. Such a device, which
offers potentially low cost and high reliability,
may be of value to the underdeveloped areas of the
world. Pumping applications may be found in other
situations where heat is more readily available than
electricity.

A theoretical basis for design has been sketched out,
although it is clear that a full understanding of the
interaction between various machine parameters has
yet to be achieved. In particular, the effects of heat
transfer limitations and of thermal losses (through the
walls of the machine and through the movement of
heated portions of the liquid) require attention.
Thermal and gas flow losses in the regenerator have not
been considered in this paper. Although the concept
of jet stream feedback is established, no· design theory
is yet available. This is a major draw back to the
creation of an optimum machine design, although
experiments have shown that it is not at all difficult
to build working machines using this principle.

Once the concept of the Fluidyne has been grasped,
many alternative configurations come to mind. Not
all of these have been tried, and it is likely that for
many applications other forms than those discussed in
this report will offer important advantages.

The cross section of the cavities need not be circular -
a prime advantage of the liquid piston scheme is that the
piston will exactly fit any shape of cylinder.
Increasing the surface/cross sectional area ratio by
departing from circular cross section or by subdividing
the cavity would improve heat transfer to the gas at the
expense of increased viscous losses. The heat flux
through the walls could also be lowered in this way,
if this would more closely match the available heat
source.

Acknowledgements

References

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(2) J.N. Mattavi, F.E. Heffner and A.A. Miklos, General Motors Corporation Research Publication GMR-936

(3) N.V. Phillips Gloeilampenfabrieken "Hot Gas Engines and Refrigerating Engines and Heat Pumps Operating on the Reversed Hot Gas Engine Principle" Brit.Pat. No.694, 856 published July 29, 1953.

(4) N.V. Phillips Gloeilampenfabrieken "Thermodynamic Reciprocating Machines" Brit. Pat. No.1, 064, 733 published April 5, 1967.

(5) R.H. Sabersky and A.J. Acosta "Fluid Flow" Collier-Macmillan Ltd. London, 1964.

LIST OF SYMBOLS

A	Area of hot and cold end liquid columns
A_0	Area of output column
A_1	Cross sectional area of displacer cavities
A_2	Cross sectional area of displacer connecting tube
d	Diameter of tube
g	Acceleration due to gravity
l	Length of displacer connecting tube
l_c	Length of cold end liquid column
l_h	Length of hot end liquid column
l_o	Length of output liquid column
$\bar{p}$	Mean pressure of working fluid
P_c	Pressure of liquid in reservoir
P_e	Pressure of working fluid
Q	Quality factor of resonant system
R_e	Reynolds number
T_c	Cold end temperature
T_h	Hot end temperature
U	Velocity of liquid (averaged over tube cross section)
V_c	Volume of working fluid at cold end of machine
V_e	Volume swept by displacer
V_h	Volume of working fluid at hot end of machine

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V_m	Total volume of working fluid at midstroke
V_o	Volume swept by output column
W_{out}	Power output of loss-less machine
x	Displacement of liquid at hot end
$\hat{x}$	Peak displacement of liquid at hot end
y	Displacement of liquid at cold end
$\hat{y}$	Peak displacement of liquid at cold end
z	Displacement of liquid in output column
ΔP	Amplitude of pressure change due to displacer action
ΔP_{visc}	Pressure drop along output column due to liquid viscosity
ΔP_1	Amplitude of pressure change due to total volume change
η	Liquid viscosity
ρ	Liquid density in displacer
ρ_o	Liquid density in output column
θ	Phase angle between displacer and output movements
ω	Operating angular frequency
ω_c	Resonant angular frequency of the cold column alone
ω_d	Resonant angular frequency of the displacer
ω_h	Resonant angular frequency of the hot column alone

APPENDIX 1

BASIC DESIGN THEORY

1. Displacer Design

We consider a displacer consisting of two cavities of cross sectional area A_1 connected by a circular tube of area A_2 and length l (figure 7). The connecting tube is assumed to be long compared with the liquid column length in each cavity. Then a small displacement x from the equilibrium level of one free surface (and hence a displacement $-x$ at the other surface) will give rise to a pressure difference $2\rho gx$ across the connecting tube, and this must be balanced by the inertial and viscous forces acting on the liquid.

$$2\rho gx + \rho l \frac{A_1}{A_2} \ddot{x} + 8\pi\eta\, l \frac{A_1}{A_2^2} \dot{x} = 0 \tag{1}$$

(a displacement x of the free surface will move the liquid in A_2 by $\frac{A_1}{A_2} x$)

The second term in (1) is the inertial term, and the third represents forces due to

viscous drag, assuming that the flow is laminar and the Poiseuille-Hagen law is applicable. When viscous losses are small, this corresponds to damped simple harmonic motion of angular frequency ω_d

$$\omega_d \approx \sqrt{\frac{2g}{l} \frac{A_2}{A_1}} \tag{2}$$

and quality factor Q

$$Q = \omega_d \frac{\rho A_2}{8\pi\eta} \tag{3}$$

It is also interesting to determine the Reynolds number of the flow in the pipe:

$$R_e = \frac{\rho\, Ud}{\eta} = \frac{\rho}{\eta} \frac{\omega_d\, V_e}{2A_2} \sqrt{\frac{4}{\pi}\cdot A_2} \qquad \text{at peak volume flow rate}$$

$$= \frac{\rho}{\eta} \omega_d V_e \sqrt{\frac{1}{\pi A_2}} \tag{4}$$

V_e is the volume swept by the displacer. (Writing A_1 in place of A_2 will give the Reynolds number for the liquid flow within the cavity.)

For water $\rho = 1$ g/cc, $\eta = 10^{-2}$ poise so at 1 c.p.s. and with a V_e of, say, 50 c.c., the peak Reynolds number will be below the critical value of $\approx 2{,}500$ only if $A_2 > 16\pi$ cm^2. (this corresponds to a pipe diameter of approximately 8 cms.) From equation (3) we find that a pipe of this size should show a Q factor of over 1,000.

A 2 cm diameter tube would have a Q according to equation (3) of 75. However, the Reynolds number would be $\sim 10^4$ and figures 5.4, 5.5 reference 5 suggest that for commercially available pipes, the losses in this region may be about five times larger than expected for laminar flow. Thus the Q would still be about 15.

2. Output Power

Now consider the complete machine, as shown in figure 1. The pressure of the working fluid (gas) is time dependent because the displacer action causes temperature changes in the gas and because movement of the output column changes the total volume of the machine. We consider these effects separately, and approximately, supposing all changes to be sinusoidal.

Firstly, suppose that the machine is at uniform temperature, then if the working fluid is ideal

$$\frac{\overline{P} + \Delta P_1}{\overline{P} - \Delta P_1} = \frac{V_m + V_o/2}{V_m - V_o/2} \tag{5}$$

(the ratio of the pressures is the ratio of the volumes).

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$$\therefore \quad \Delta P_1 = \frac{\bar{P}}{2} \frac{V_o}{V_m} \tag{6}$$

This pressure change does no work because it is 90° out of phase with the rate of change of volume (180° out of phase with volume change).

For an approximation to the pressure amplitude, ΔP, due to displacer movement, suppose that the midstroke volume (i.e. the volume with the output column in its midstroke position) is equally distributed between hot and cold ends, when the displacer is central, and that the gas is always at either the hot or the cold temperature.

$$(\bar{P} + \Delta P) \left(\frac{V_m/2 + V_c/2}{T_h} + \frac{V_m/2 - V_c/2}{T_c} \right)$$

$$= (\bar{P} - \Delta P) \left(\frac{V_m/2 - V_c/2}{T_h} + \frac{V_m/2 - V_c/2}{T_c} \right) \tag{7}$$

since in these circumstances

$$\frac{PV_h}{T_h} + \frac{PV_c}{T_c} = \text{constant}, \text{ if the mass of working fluid is constant. Rearranging (7) we}$$

have

$$\Delta P = \bar{P} \frac{V_c}{V_m} \left(\frac{T_h - T_c}{T_h + T_c} \right) \tag{8}$$

Now, suppose that the hot cavity volume leads the total volume by θ (i.e. the phase angle between the displacer and output columns is θ). The instantaneous rate of working is given by the product of pressure and rate of change of volume. The average power output assuming sinusoidal changes is of course half the peak pressure, ΔP, x the peak rate of change of volume the x sine of the phase angle between them.

$$W_{out} = \frac{1}{2} (\Delta P) \left(\frac{\omega V_o}{2} \right) \sin \theta$$

and substituting for ΔP this becomes

$$W_{out} = \omega \bar{P} V_o \frac{V_c}{4V_m} \left(\frac{T_h - T_c}{T_h + T_c} \right) \sin \theta \tag{9}$$

This is the power available for the output and to overcome losses in the pipework. We note that, other parameters being constant, it is maximum when $\theta = \pi/2$.

Similar arguments apply to machines with the hot and cold cavities combined (e.g. figure 4).

3. Output Column Design

We now consider the design of the output column. The pressure changes which are 180° out of phase with V_o, and hence with output column displacement, are to be balanced by the

inertia of the liquid in the tube, most of whose length has cross sectional area A_0. We shall neglect the restoring force of gravity in the output column.

$$\Delta P_1 - \Delta P \cos \theta + \rho_0 l_0 \ddot{z} = 0 \qquad (10)$$

$\ddot{z}$ is the acceleration of the output liquid column. Substituting for ΔP_1 and ΔP from (6) and (8) equating the peak values (since we are considering only forces in phase with acceleration).

$$\frac{\bar{P} V_0}{2V_m} - \frac{\bar{P} V_c}{V_m} \left(\frac{T_h - T_c}{T_h + T_c} \right) \cos \theta + \rho_0 l_0 \ddot{z} = 0$$

and $\ddot{z} = -\omega^2 z = \omega^2 \dfrac{V_0}{2A_0}$ where ω is the operating frequency

$$\therefore \quad \bar{P} \frac{V_0}{V_m} \left\{ \frac{1}{2} - \frac{V_c}{V_0} \left(\frac{T_h - T_c}{T_h + T_c} \right) \cos \theta \right\} = \frac{\omega^2 V_0 \rho_0 l_0}{2 A_0} \qquad (11)$$

$$\therefore \quad l_0 = \frac{A_0 \bar{P}}{\omega^2 \rho_0 V_m} \left\{ 1 - \frac{2V_e}{V_0} \left(\frac{T_h - T_c}{T_h + T_c} \right) \cos \theta \right\} \qquad (12)$$

The second term in curly brackets is often negligible, since we may be limited by the properties of the liquid to a low hot end temperature, T_h, and to maximise output we shall want θ close to $\pi/2$. In that case

$$l_0 \approx \frac{\bar{P} A_0}{\omega^2 \rho_0 V_m} . \qquad (13)$$

This tells us the relationship between the length and the area of the output column and other parameters.

The pressure drop along the output tube due to viscosity, again assuming the Poissieulle - Hagen law, is

$$\Delta P_{visc} = \frac{8\pi \eta l_0 \, \omega \, V_0/2}{A_0^2} \qquad (14)$$

and if most of the available power is not to be taken up in the output line we must have

$$\Delta P_{visc} < < \Delta P \sin \theta$$

substituting for ΔP_{visc} and ΔP yields

$$l_0 > > \frac{\bar{P} V_c}{V_0 V_m} \cdot \frac{A_0^2}{4\pi \eta \, \omega} \left(\frac{T_h - T_c}{T_h + T_c} \right) \sin \theta \qquad (15)$$

and inserting the approximate value for l_o from (15),

$$\frac{\omega \rho_o \, A_o \, V_e}{4\pi\eta \, V_o} \left(\frac{T_h - T_c}{T_h + T_c} \right) \sin \theta \gg 1. \tag{16}$$

This sets a lower limit on A_o, and hence on l_o.

$$A_o \gg \frac{4\pi\eta \, V_o}{\omega \, \rho_o \, V_e \, \sin \theta} \left(\frac{T_h + T_c}{T_h - T_c} \right) \tag{17}$$

so that

$$l_o \gg \frac{4\pi\eta \, V_o \, \bar{P}}{\omega^3 \, \rho_o^{\,2} \, V_e \, V_m \, \sin \theta} \left(\frac{T_h + T_c}{T_h - T_c} \right) \tag{18}$$

Note, however, that we have assumed laminar flow. The Reynold's number in the output column may be found from equation (4) by an obvious change of symbols, and if turbulent flow is to be expected, modifications to the criteria in (15) - (18) will be required.

Some of the remaining power is to be fed back to overcome displacer losses (which are usually small compared to the losses in the output column). The available output power after all these losses are accounted for may be equated to the potential and kinetic energy given to the liquid if the machine is to be used in pumping applications.

A similar set of arguments maybe applied to the design of combined cold cavity machines (e.g. figure 4).

It is clear from the experimental experience which has been gained that the presence of valves in the output line modifies its tuning properties, particularly as the pumping head is increased. No account has been taken of this in the above analysis, although a proper understanding of the effect is clearly essential if optimum coupling between the Fluidyne and a pumping system is to be achieved.

Cooke-Yarborough has suggested that instead of the placing the pumping lines effectively in series with the output line (figure 5) there would be some advantages to a parallel arrangement (figure 9). Such a configuration has been shown to work satisfactorily, but the circumstances most appropriate to each scheme have not yet been delineated.

APPENDIX 2

PRESSURE FEEDBACK

In this configuration, Figure 8, the alternating pressure difference across the hot column and across the cold column is $P_e - P_c$, where P_e is the pressure of the working fluid, and P_c the pressure in the large container.

We have (assuming the same liquid throughout)

$$P_c(t) + \rho l_0 \ddot{z} + \frac{8\pi \eta l}{A_0} \dot{z} = 0 \tag{1}$$

neglecting the restoring force of gravity on the output column.

$$P_e(t) - P_c(t) + \rho l_h \ddot{x} + \frac{8\pi \eta l_h}{A} \dot{x} + \rho g x = 0 \tag{2}$$

$$P_e(t) - P_c(t) + \rho l_c \ddot{y} + \frac{8\pi \eta l}{A} \dot{y} + \rho g y = 0 \tag{3}$$

we also have $A(x + y) = A_0 z$

and

$$P_e(t) \left(\frac{V_m/2 + A x}{T_h} + \frac{V_m/2 + A y}{T_c} \right) = \text{a constant} \tag{4}$$

For simplicity, let us assume that we require the two cavity volume changes to be of equal amplitude and in quadrature.

i.e. $x(t) = \hat{x} \cos \omega t$

$y(t) = \hat{y} \sin \omega t$

with $\hat{x} = \hat{y}$. ω is the operating frequency.

Equating components of (2) and (3) which are in phase with y gives

$$- \rho l_c \omega^2 \hat{y} + \rho g \hat{y} = - \frac{8\pi \eta \omega l_h}{A} \hat{x} \tag{5}$$

and equating components in phase with x yields

$$- \rho l_h \omega^2 \hat{x} + \rho g \hat{x} = \frac{8\pi \eta \omega l_c}{A} \hat{y} \tag{6}$$

substituting $\hat{x} = \hat{y}$ and manipulating these equations we find

$$l_c - l_h = \frac{8\pi \eta}{A \rho \omega} (l_c + l_h) \tag{7}$$

The right hand side of this equation is positive, and therefore the cold column must be made longer than the hot, and hence of lower resonant frequency. We can also show that the operating frequency, ω, lies between the frequencies which the hot and cold columns

would have alone:

writing $\omega_h = \sqrt{\dfrac{g}{l_h}}$

where ω_h is the resonant frequency of the hot column alone (from equation (2) neglecting damping) and substituting this into (5) yields

$$\frac{8\pi\omega\eta l_c}{A} = \rho g\left(1 - \frac{\omega^2}{\omega_h^2}\right) \tag{8}$$

The L.H.S. is positive, and therefore $\omega < \omega_h$. A similar argument shows that $\omega > \omega_c$.

$$\frac{8\pi\omega\eta l_h}{A} = \rho g\left(\frac{\omega^2}{\omega_c^2} - 1\right) \tag{9}$$

Fulfillment of these conditions makes the left hand sides of equations (2) and (3) equal for arbitrary values of $P_e - P_c$ so that for any pressure difference between the working fluid and the container, the two columns will be driven to equal amplitudes, with the cold cavity volume lagging the hot by 90°, as required. In fact, we have made the mechanical impedances of the two columns equal in amplitude and 90° out of phase. Moreover it is known (see e.g. Appendix 1) that with the hot cavity volume leading the cold cavity volume, the pressure P_e has a component capable of doing work. Thus, an arbitrary pressure change will lead to changes in the cavity volumes which cause the pressure to vary in the desired manner. The device will therefore run as an engine provided the output column is correctly tuned.

APPENDIX 3

### SOME ALTERNATIVE CONFIGURATIONS

A number of alternative configurations for the Fluidyne type of machine have been suggested. Three of these are outlined below.

(1) Figure 10. This is a variation on the jet-stream feedback system which is particularly easy to construct and operate. As shown, much of the output tube can be contained within the envelope of the reservoir, leading to a fairly compact package. Experience has shown that whilst this layout makes an attractive demonstration model, it is sometimes rather difficult for onlookers to grasp the mechanism of operation. The presence inside one liquid column of the end of the output tube alters the resonant frequency of that column, so that there is presumably some element of pressure feedback. In fact a little thought shows that this effect will tend to be the opposite from that

achieved by making the cold column longest. Apparently the jet-stream feedback provides sufficient coupling to overcome this.

(2) Figure 11. Again, jet-stream feedback is used but in this scheme the pumped water passes through the hot cavity. If heat can be supplied at a sufficiently high rate, the machine will pump in cold water and pump out hot water. It has the advantage (if used as a combined pump/heater) that heat conducted down the walls is not wasted, but is used to preheat the water. No attempt has been made to prove this type of device experimentally. There are several obvious variants.

(3) In this arrangement the liquid in the output columns is separated from the liquid in the reservoir and cavities by a flexible membrane (figure 12a), although a bellows or diaphragm could also be used. Figure 12b shows a potentially useful configuration where the pumped liquid is contained by a membrane. In either case, pressure feedback or jet-stream feedback may be used – one way of achieving the latter is suggested by the broken lines in figure 12a. If the parallel arrangement of pumping lines is preferred, the configurations of figure 12 may be combined with that of figure 10. No machines of this type have been built.
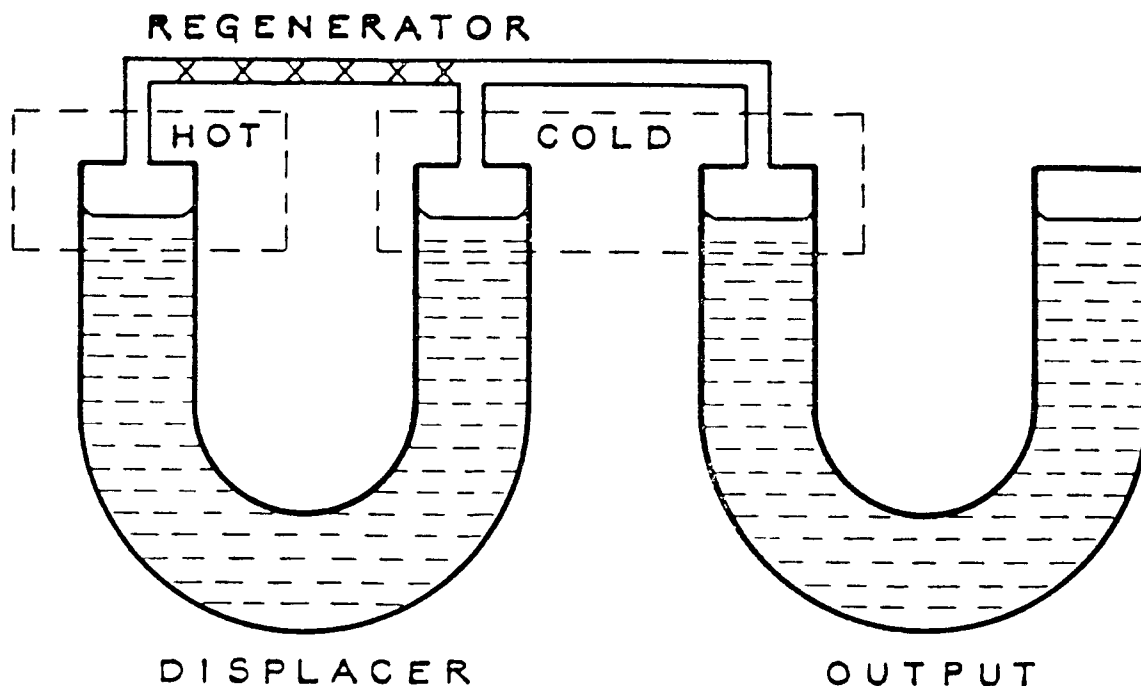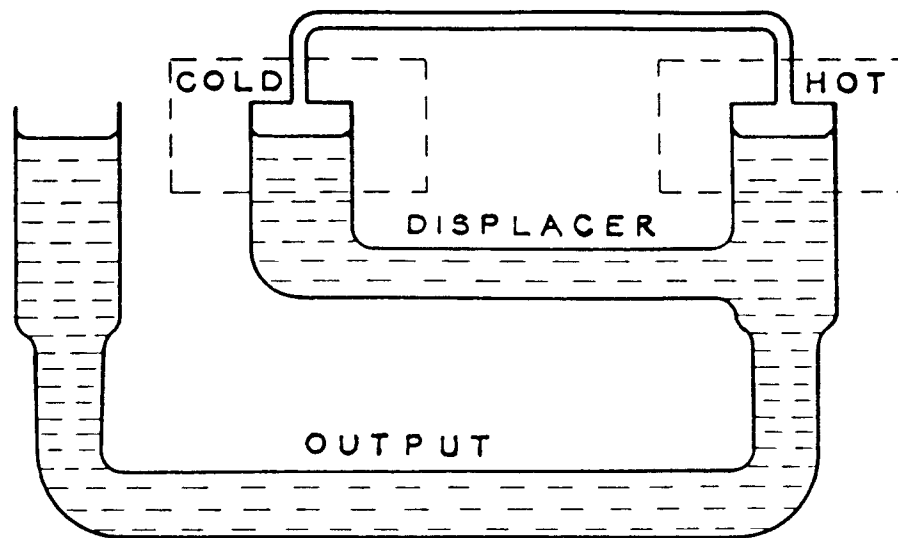

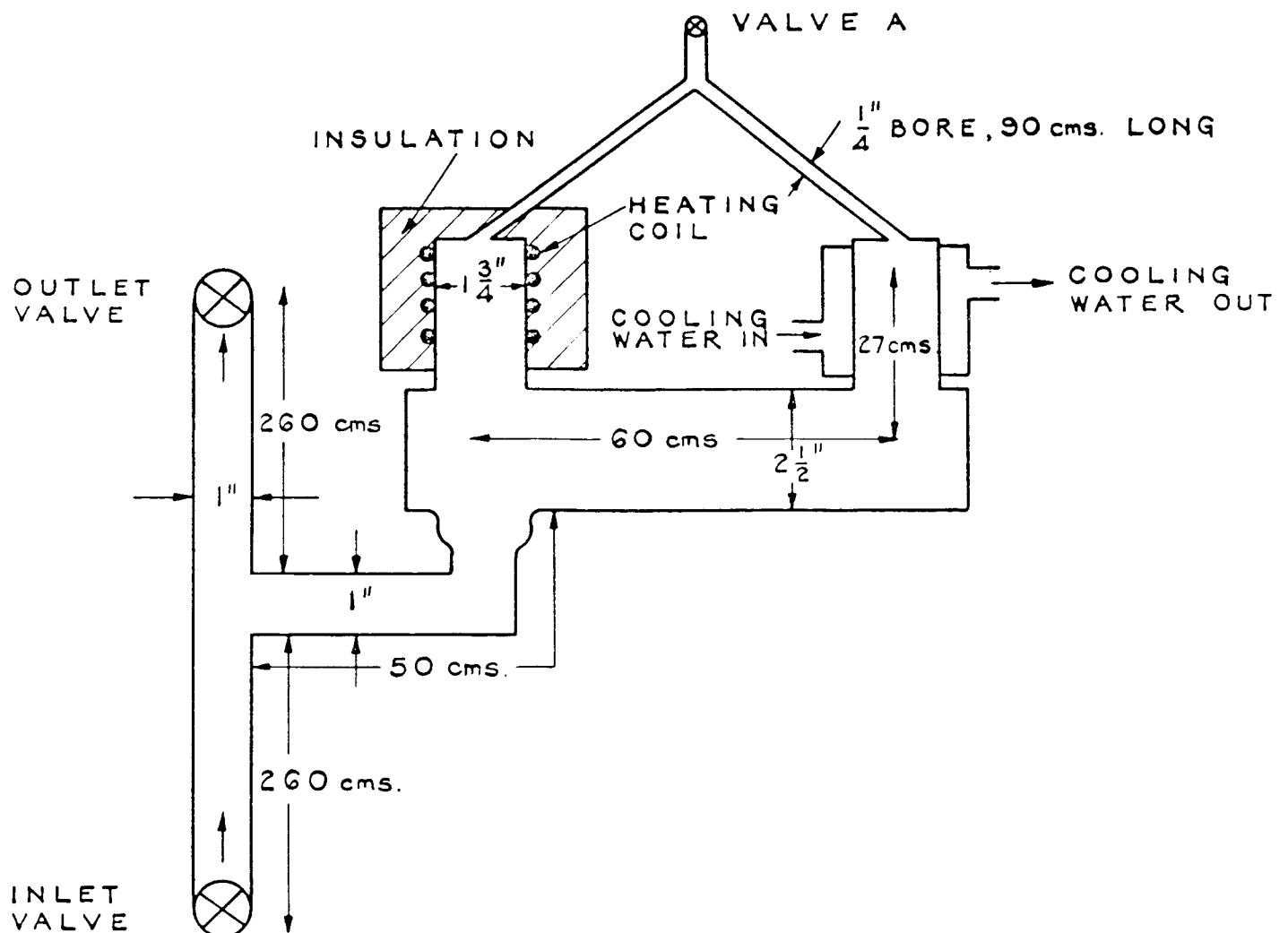A. E. R. E.   R 6 7 7 5 .   F I G . I .
T H E   B A S I C   F L U I D Y N E

HEAT IN

A

S
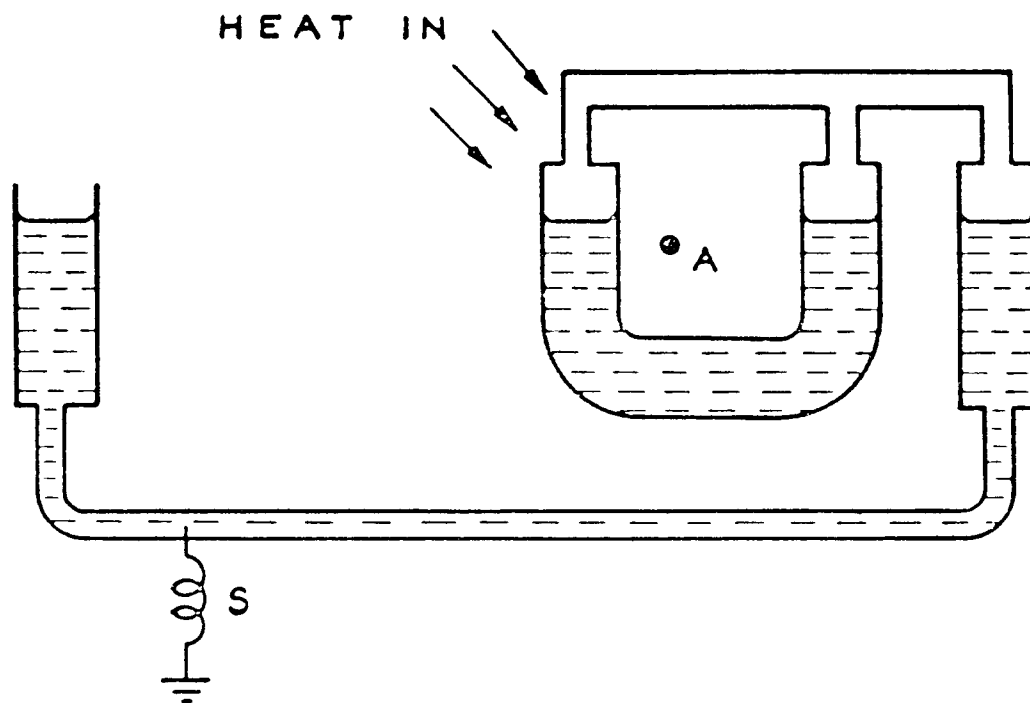
A.E.R.E. R6775. FIG.2.
ROCKING BEAM FEEDBACK

COLD HOT

OUTPUT
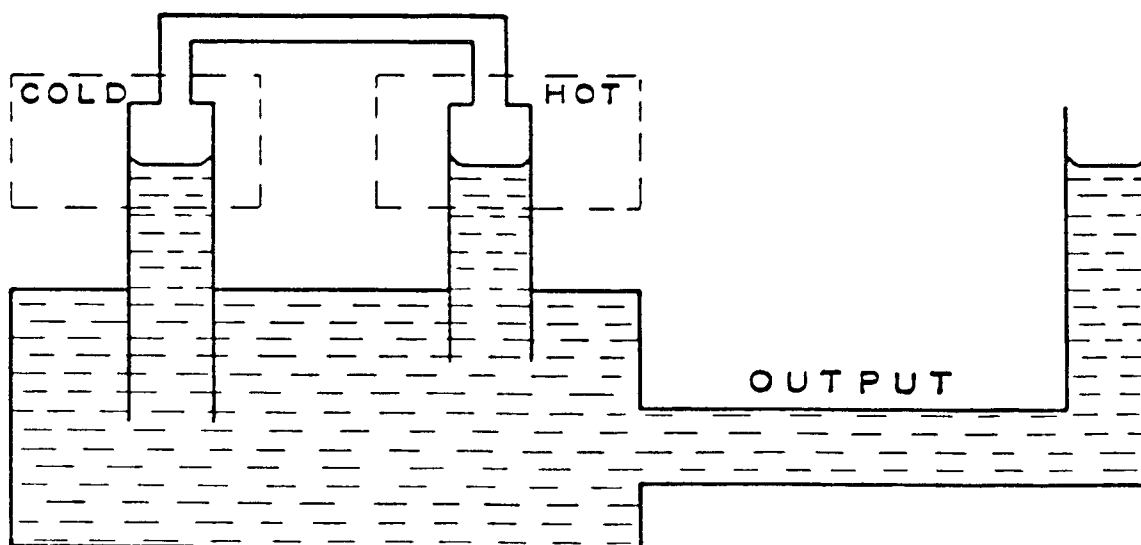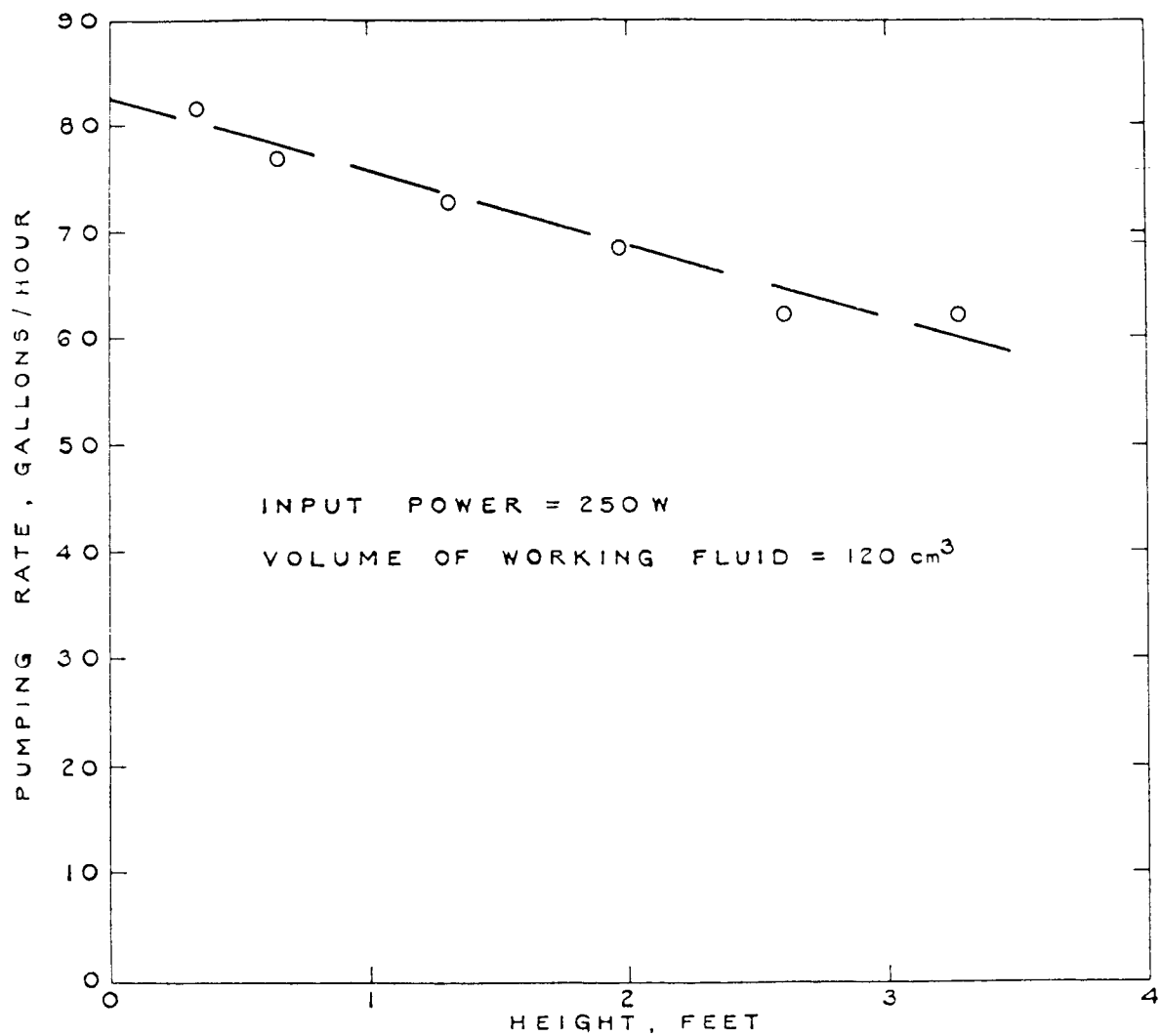
A.E.R.E. R6775. FIG.3.
PRESSURE FEEDBACK

A. E. R. E. R 6775. FIG. 4.
JET STREAM FEEDBACK

A.E.R.E. R6775. FIG. 5. FLUIDYNE PUMP

A.E.R.E. R6775. FIG.6.
PUMPING RATE vs. HEAD
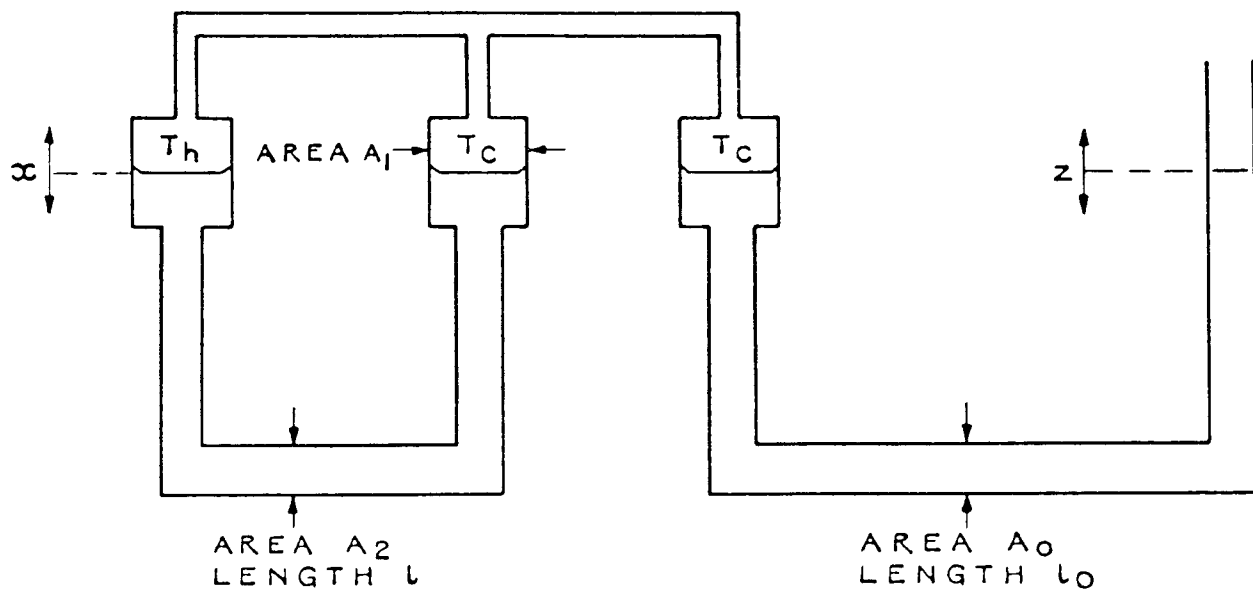
A.E.R.E. R6775. FIG.7.
BASIC MACHINE - SYMBOLS
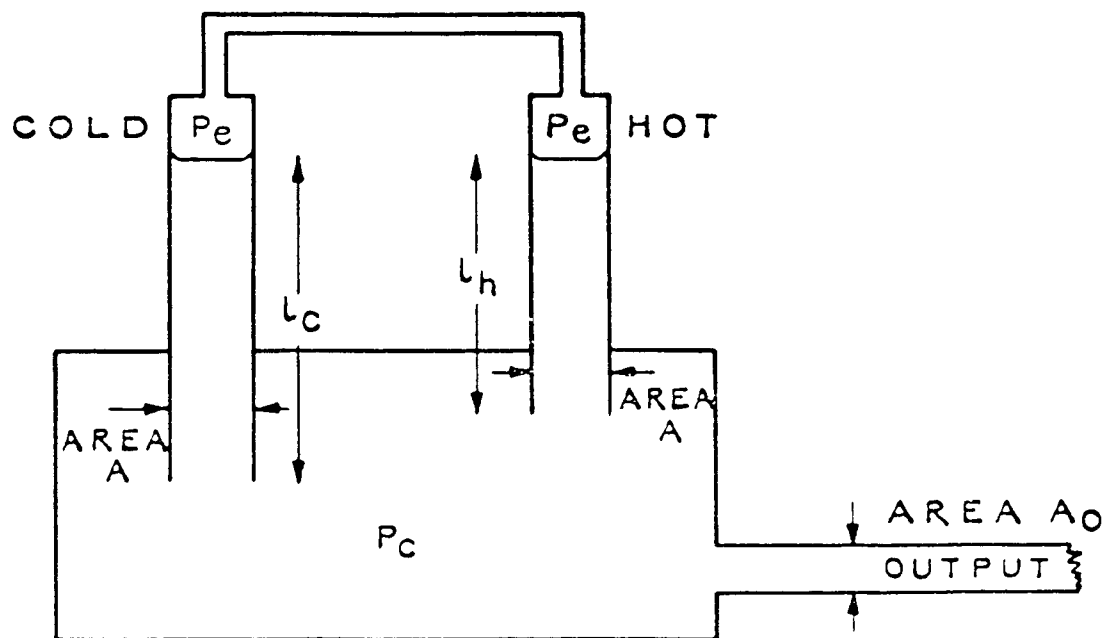
A . E . R . E .   R 6775 .   F I G . 8 .
PRESSURE   FEEDBACK – SYMBOLS
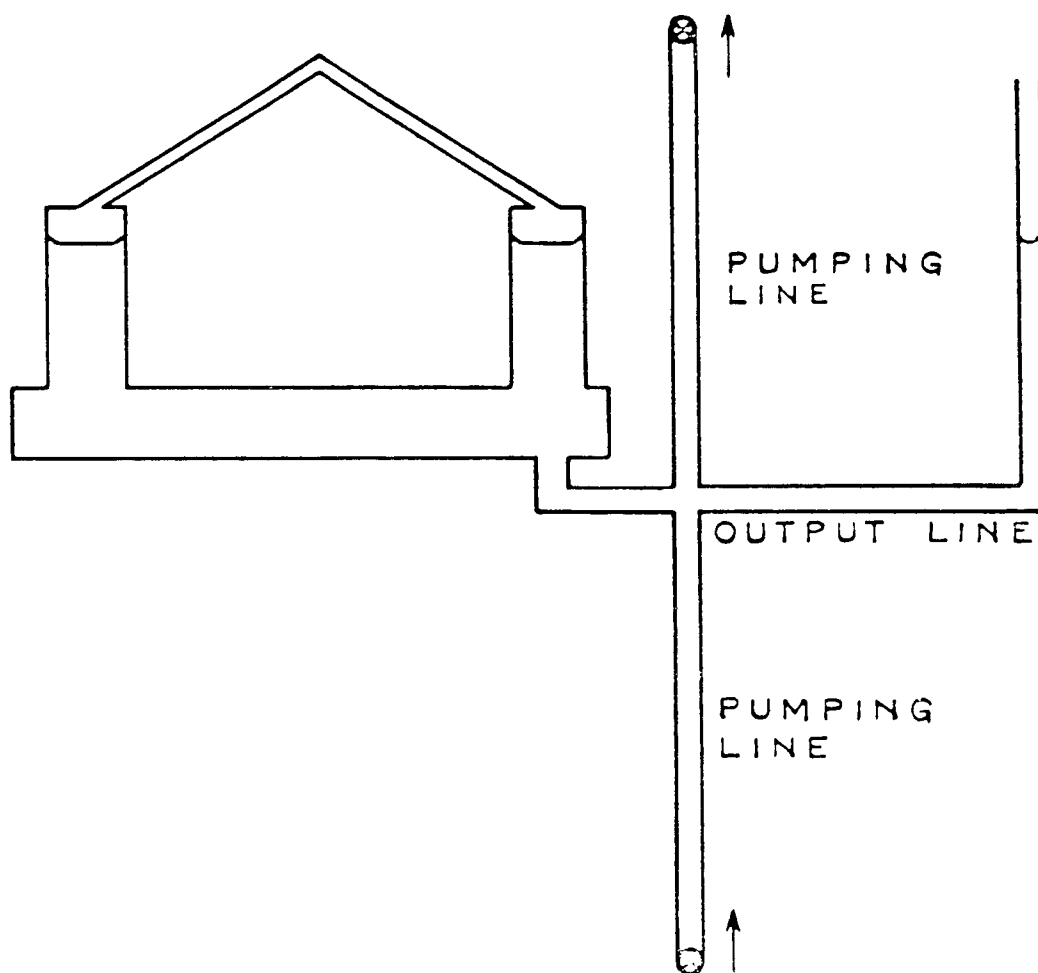
A.E.R.E.   R 6775 .   FIG.9 .   PARALLEL
PUMPING   AND   OUTPUT   LINES .

HOT COLD

RESERVOIR

OUTPUT LINE
COILED IN
RESERVOIR
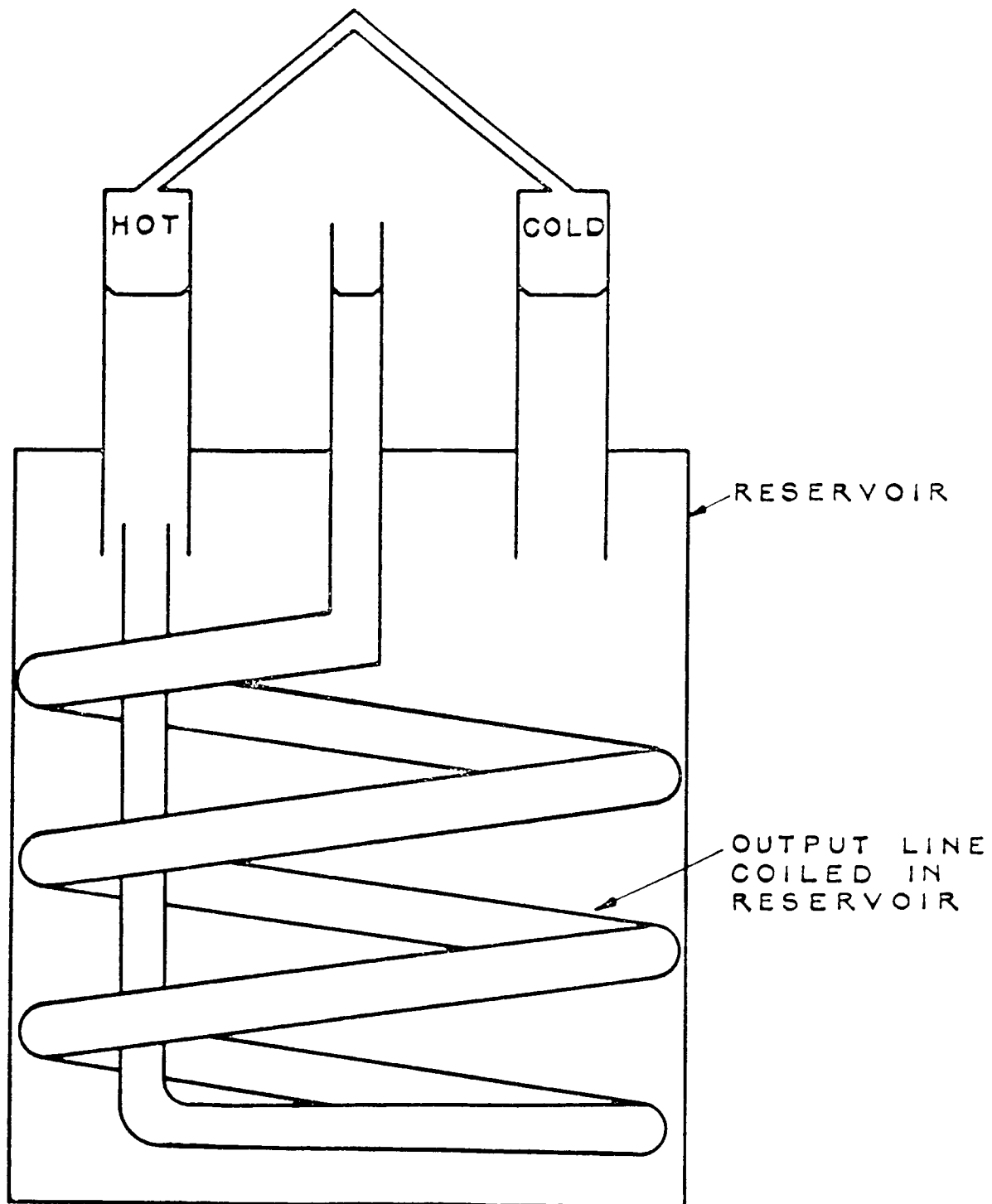
A.E.R.E. R6775. FIG.10. ALTERNATIVE
CONFIGURATION FOR JET-STREAM
FEEDBACK
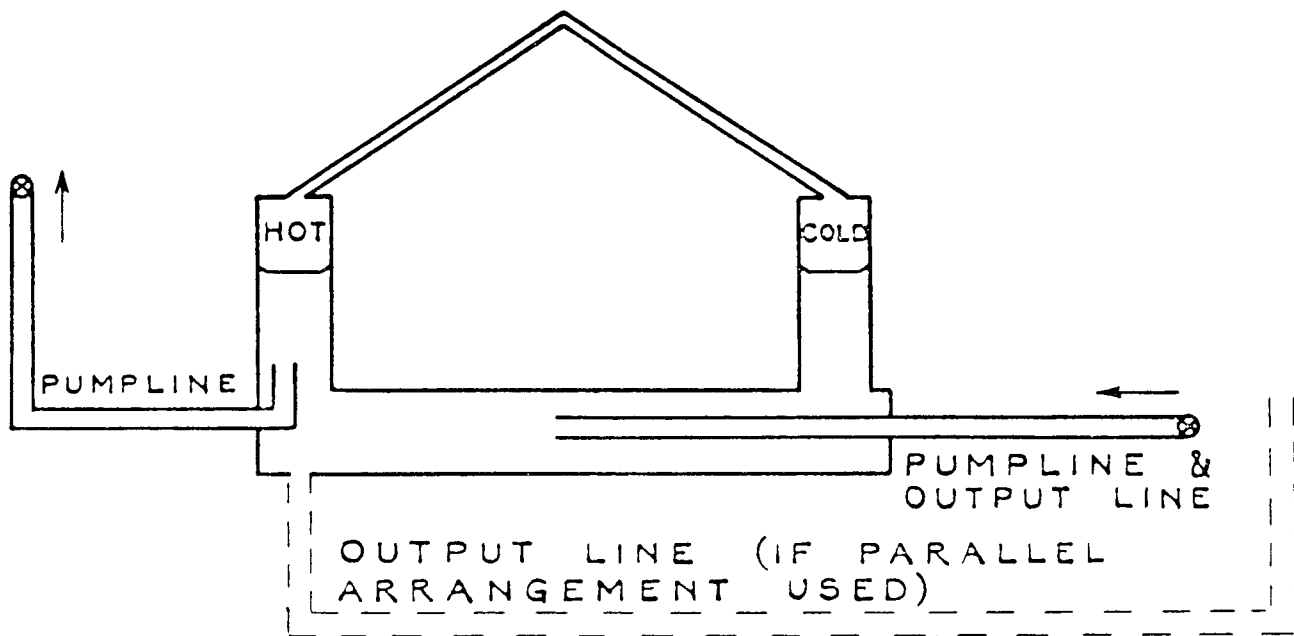
A.E.R.E. R6775. FIG.II.
COMBINED PUMP/WATER HEATER

(a)

FLEXIBLE BAG

OUTPUT LINE

(b)

FLEXIBLE MEMBRANE

PUMPING LINE

PUMPING LINE
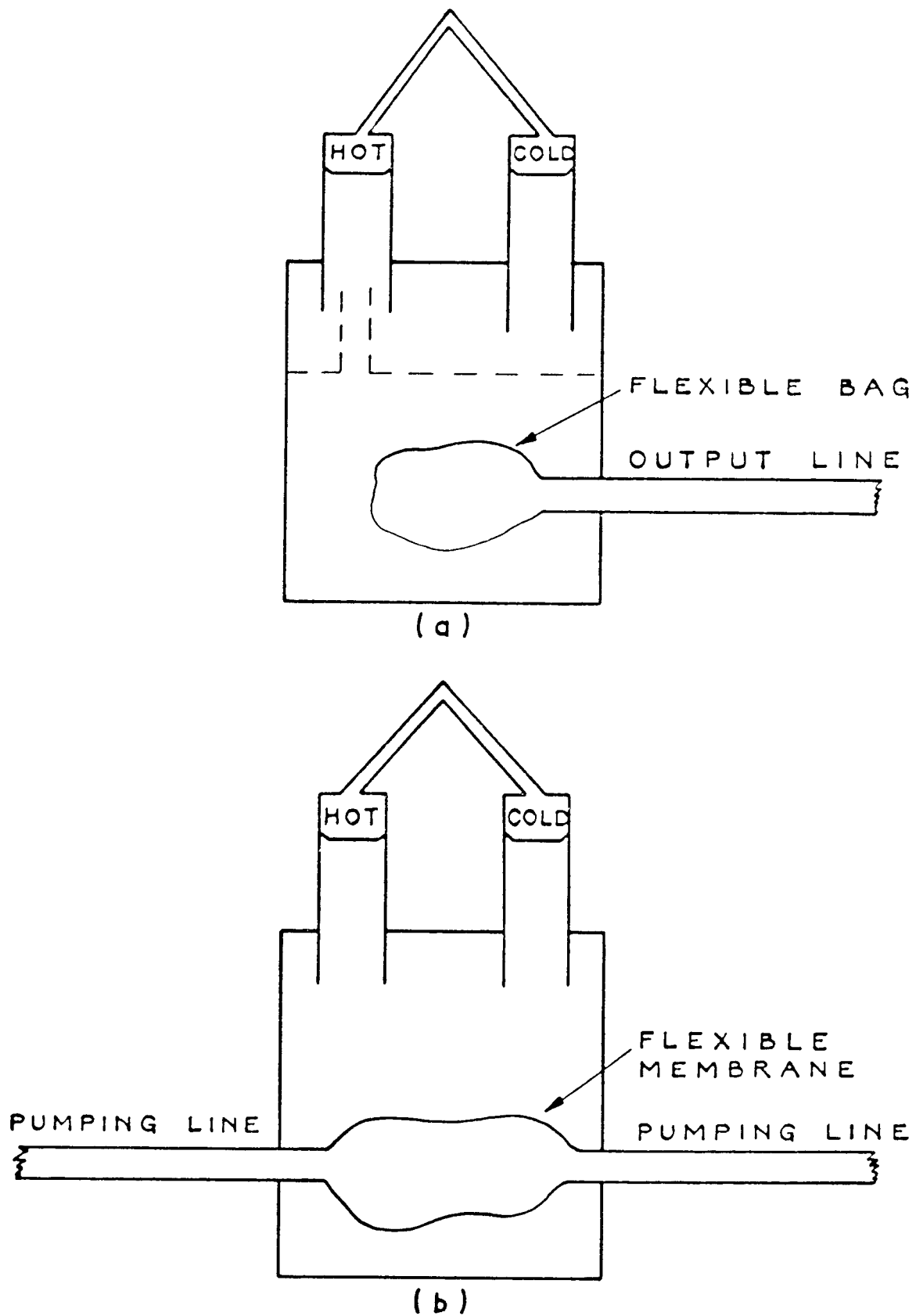
A.E.R.E. R6775. FIG.12.
CONFIGURATION SEPARATING
OUTPUT AND CAVITY LIQUIDS

Aerospace Propulsion Powerplants
by Lawrence T. Cargnino & Clifford H.Karvinen
4th Ed. c 1967 Educational Publishers, Inc., Chicago
p. 562-5

The Intermittent-firing Duct (Pulse Jet).— The intermittent firing duct, or pulse jet, is so named because its jet stream issues from the nozzle in
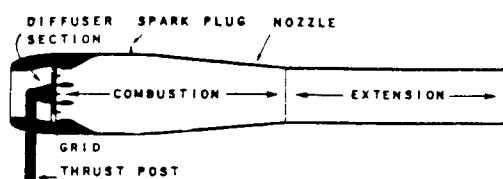
Figure 510 - Schematic arrangement of parts in a pulse jet engine.

periodic bursts rather than in a continuous stream. To simplify the nomenclature and yet retain a name descriptive of the unit, the name "pulse jet" has been accepted as an official designation.

The essential features of a pulse jet engine are shown schematically in Figure 510. The grid is the most important mechanism in the design of the pulse jet engine. It consists of the air intake flapper valves, fuel lines, fuel nozzles, starting fuel lines, and starting fuel nozzles. The air intake flapper valves consist of "V" section supporting members fitted with strips of spring steel (Figure 511). The spring steel strips exert pressure against the support members so that, with equal pressures on both sides of the grid, the valves will

Figure 511 - Air intake flapper valve arrangement, pulse jet engines.

present a series of closed "V's". The ends of the supporting members face forward while the V-shaped trailing edges point toward the combustion chamber behind the grid. In operation, the springs permit passage of air through the "V" section when the pressure differential between the diffuser section and the combustion chamber is sufficient to overcome the resistance of the spri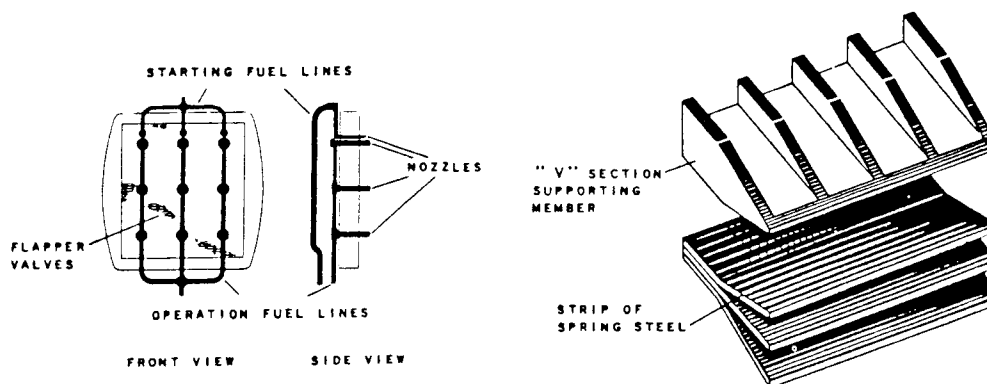ng leaves. When the pressure differential decreases sufficiently, the spring steel leaves return to their closed position and prevent entry of air from the diffuser section. Increase in pressure in the combustion chamber assists in keeping the valve closed. The design of the flapper valve unit is such that alternate layers of spring steel and supporting members may be assembled into a grid of any desired dimensions. In this manner, varying degrees of thrust up to several thousand pounds can be obtained.

Operation.- In starting the pulse jet engine, compressed air from an external source is supplied at 180 to 200 p.s.i. to compressed air nozzles that are located immediately above the upper row of fuel jets. The air pressure opens the fuel valve and automatically restricts, to a predetermined amount, the fuel flow which passes to the grid. An ordinary spark plug located on the casing provides the spark to ignite and burn the fuel-air mixture. The heat generated by combustion raises the temperature of the air and starts the reaction. The three starting jets, like the ignition device, are used for starting only. The residual flame, which is left in the combustion chamber after each discharge, ignites the new charge and thereby continues the reaction.

In flight, air is forced into the combustion chamber by ram effect. However to obtain sufficient mass flow of air to maintain operation of the engine and flight of the aircraft, it is necessary to give the aircraft an initial forward velocity by some type of launching device, When the air valves are forced open
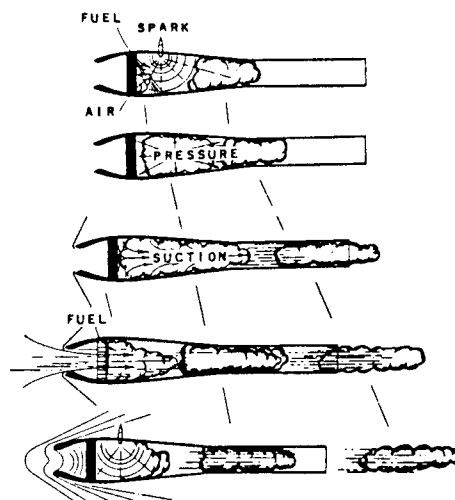

Figure 512 - Complete cycle of operation of a pulse jet.

by ram air pressure, air enters the combustion chamber and mixes with the fuel. This mixture is ignited by the residual flame and the release of the heat energy in the fuel causes a rapid rise in pressure within the combustion chamber. This pressure closes the air valves and accelerates the gases, forcing them through the tailpipe at high velocity. The reaction to this accelerating force causes a thrust force to act on the closed (grid) end of the combustion chamber.

Due to the momentum of the gases passing through the tailpipe, the pressure in the combustion chamber drops rapidly, creating a partial vacuum. When the pressure differential across the air valves exceeds the closing pressure of the springs, the combustion chamber is recharged with air and atomized fuel. This new charge is then ignited by the residual flame and the cycle is repeated.

The complete cycle of operation of the pulse jet is shown in Figure 512.

The cycling operation of the pulse jet continues at a frequency determined by the length of the duct, the temperature of the combustion gases, the inlet ram pressure, and the change in altitude. The German V-1 (or buzz bomb), for example, fired at the rate of about 40 times per second.

The pulse jet is able to develop some thrust at rest because its construction is such that it is able to induct some air even at a standstill.

The thermal efficiency of this device improves with increase in speed due to increase in compression ratio. At speeds approaching sound velocity, however, the operation of the inlet air valves begins to be affected. The practical upper limit of speed for the pulse jet is probably in the order of 600 m.p.h.

The propulsive efficiency of the pulse jet is fairly good because of its relatively low jet velocity. However, its over-all efficiency is low due to poor conversion of fuel energy at low values of compression ratio.

IX. Vortices of Air, Fire, and Water

Vortices in the atmosphere range in size from snow or dust devils and fire whirls to the waterspout, tornado, and fire storm, to the massive organized storm systems epitomized by the hurricane and typhoon over the oceans and continent-wide low pressure storms over the land. For experimental purposes we will limit ourselves to modeling the tornado, the whirlpool, and the fire whirl (this latter structure is somewhat akin to the dust devil). They all have features in common.

The most impressive demonstration simulates a tornado and requires a circular metal container with a diameter about ⅓-½ of its height. The smallest practical size is a 4-liter (1 gal.) can; the largest is an oil drum with a capacity of 220 liters (55 gals.). The other items needed are an old-fashioned vacuum cleaner that sucks air in a swirling motion, enough hot water to cover the bottom of the tornado chamber 2 cm deep, and a projection-type floodlight for illuminating the inside of the chamber. Fig. 40 shows a unit made from an oil drum.

A rectangular hole is cut into the side of the container. This should be centrally located; its height should be about half the height of the can, and its width about half the diameter of the can. Two round holes are also made in the top, one in the center for the suction port of the vacuum cleaner, the other for mounting the projection lamp. For a 10- or 15-minute operation, the water in the bottom of the container can be heated to the boiling point before it is poured in.

As the velocity of the motor increases, an air vortex becomes visible. When properly formed it looks very much like a real tornado or waterspout, and a miniature column of water will actually develop where the vortex contacts the surface of the hot water.

If a chunk of dry ice is placed in the hot water, the vortex tube becomes quite spectacular. A similar effect occurs when a large number of condensation nuclei are provided, which can be done by striking a kitchen match.

A number of interesting experiments can be carried out with the vortex generator once its basic physical relationships are understood. For example, if the unit is placed in a large container fitted so that the air exhausted by the vacuum cleaner is passed again through the vortex, any airborne particles are subjected to intense "scrubbing" forces. Thus the scavenging action of a moist air vortex can be studied.

To form a beautiful whirlpool, a plastic cylinder or box with the dimensions shown in Fig. 40 provides a good starting point for experimentation. If a hole is cut in the bottom of the chamber large enough to accommodate a 2.5-cm (1 in.) cork or rubber stopper, various sizes of drain orifices can be employed to control the dimensions of the vortex. A tangential jet of water at the top of the tank drives the vortex. If an adequate supply of water is available, a tube providing water to the jet and a drain below the chamber to dispose of the water are all that is needed to carry out the demonstration. If the water supply is limited, a small water pump connecting the jet to the drain of the pan below the vortex chamber provides a closed water cycle. It is amazing how many different types of whirlpool vortices can be generated by the clever experimenter.

The third vortex demonstration is the fire whirl. In its simplest form the fire whirl may be demonstrated by using the tornado chamber. Instead of water, a can of Sterno or some other alcohol-based fire starter may be used. A large candle, a stick of burning incense, or a kerosene-fed cotton wick may be used. If large particle-producing fires are created, smoke will eventually fill the room.

Another type of fire vortex uses a fire of burning paper, cardboard, wood, pine cones, or other fuel in an area where the air enters in a tangential direction as shown in Fig. 40. Such a fire whirl closely resembles in miniature the gigantic fire whirls that often occur in a forest fire, and are dreaded by the forest-fire control experts, in which the air enters the fire at a tangent. Such fire vortices sometimes become large enough to carry burning branches into the sky and scatter them over mile-wide areas. These can cause the "blowup" — the worst kind of forest fire.

Tornado Simulator
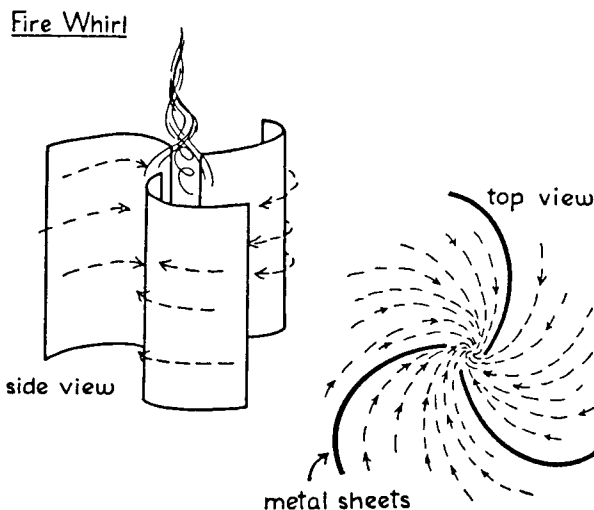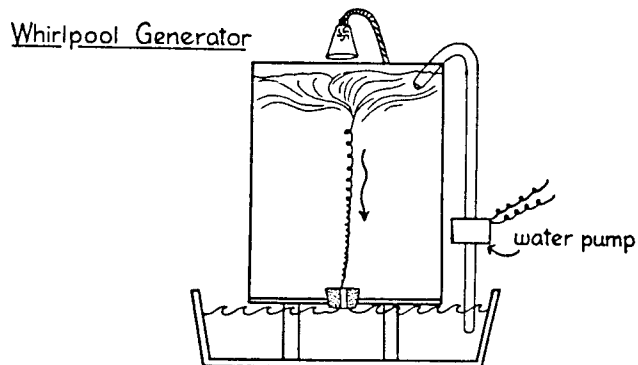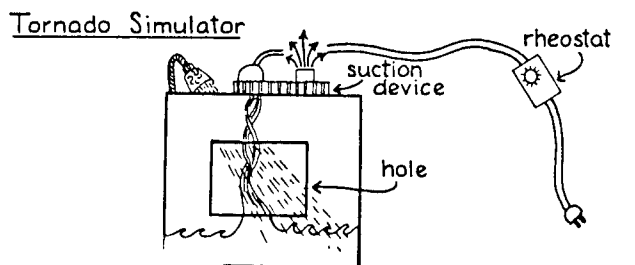
Whirlpool Generator

Fire Whirl

Fig. 40 Three types of vortices.

144

THE AL-CHOOSS GENERATOR
by
Albert Zock

        The soul of all kinds of life, culture or technology is energy.
Energy is a form of light, warmth, may it be chemical, fossil or
nuclear - in one word potential energy.

        It has been estimated that in one year man uses up energy
deposits which took nature over 2,800,000 years to accumulate and
the exploiting goes on. No wonder our planet is in such a mess and
it looks as if there is no escape out of this "Circle of Fire" -
yet, it takes only a change in direction to break out of this
vicious circle - the answer is "Soft Technology."

        Soft Technology is that which nature has used since the be-
ginning of time (if there was a beginning). Daily it lifts millions
of tons of water high into the air with a minimum of effort and
without destroying its biological quality, as conventional turbines
do.

        Our greatest energy reserve lies over 149 million kilometers
(92.5 million miles) away. From the daily supply of solar energy
(17.3×10^{16}W) nature stores 23% (4×10^{16}W) in water, steam, air
and ice. Surface water is the best storage of solar energy and the
Al-Chooss method puts it to good and clean use, which is a step
in the evolution of technology.

        Viktor Schauberger points out that the friction of the water
against the metal of turbines, which chopping it, so to speak,
looses its atomic structure - it becomes lifeless. However, one
can not only avoid this bad side effect but even enhance its
quality by changing from the centrifugal principle to the centri-
petal one - from explosion to implosion.

        Viktor Schauberger built such a generator using a kind of
curved pipes, which steer the water away from the walls inward.
Such construction increases the biological property of the water
and it also cools it down, like a water spring does. Such curves
not only improved the quality of the water, they also create an
energy which drives the generator without the need of fuel once it
has been started, and to top it all - it even has power to spare.
In other words, you get more out of it than you put in, the energy
is free...

        The Al-Chooss energy transformer in Syria, is such an inte-
grating system as well, just its construction is different. Not
only the solar energy stored in surface water but also the pressure
difference between water and air, combined with the adhesion and
cohesion forces are with a minimum of effort converted into a
potentially high energy. The exchange of energy is equal: Therm.E.=
Kin.E. = Pot.E. = Mech.E. = Electr.E....
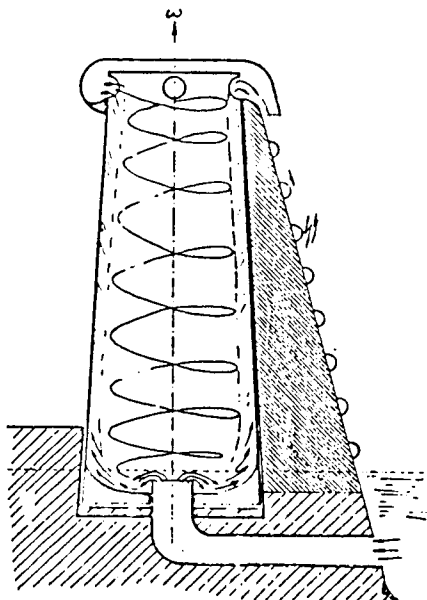
DESCRIPTION

        A tall upright standing hollow metal cylinder, with a heavy
bottomplate as flywheel, is friction free mounted to its base in

such a way, that it can be made to rotate vertically. This hollow body has a slight conical shape and its lower segments, the flywheel, bottom, base and water intake, lay beneath the water level. This construction guarantees a steady supply of water to its interior when in motion.

Like Schauberger's generator, this one also has to be started with the help of an electric motor or the like. Once in motion, because of the centrifugal force, the water climbs the wall up in a spiral which creates a vacuum on the bottom. The pressure difference between water and air will result in a steady flow into the cylinder. Because of the narrowing upper part the speed of the spiraling water increases making it not only self supporting, but even augmented as well. This act transforms heat directly into kinetic energy contrary to other methods. Other beneficial side effects of the Schauberger and Al-Chooss generators are enriched oxydation and cooling of the water while cleaning the air within the swirl. As soon as the water reaches the top, it leaves through four outlets. Its high content of potential energy makes it excellent for irrigation, or it can run over a turbine cascade into a basin and be used over and over again. Sea water can be directed back into the ocean. Dams and resevoirs are not needed. The weight proportion between watercolumn and rotating body exceeds 9:10.

Up to now small prototype bearings have been used to reduce friction between bottom flywheel and base, but to reduce friction to almost nothing, the use of magnetic fields has been suggested.

It works on the same principle as hurricanes do. In warm regions the surface water of the ocean is saturated with solar energy. The whirling currents of the sea initiate a swirl in the uprising evaporation and in time a hurricane is in full swing. A hurricane does not only support itself but its overload of energy causes destruction and even moving of heavy objects. Science does not research the implosion principle deeper because of its cooling side effect, creating heat is all they are interested in.

THE AL - CHOOSS GENERATOR.

G. CONSTANTINESCO.
146   ALTERNATING LIQUID CURRENT MOTOR.
APPLICATION FILED AUG. 25, 1921.

1,432,672.   Patented Oct. 17, 1922.

Fig.6.

Fig.4.

Fig.3.

Fig.5.

Fig.7.

Fig.8.

Fig.1.

Fig.2.
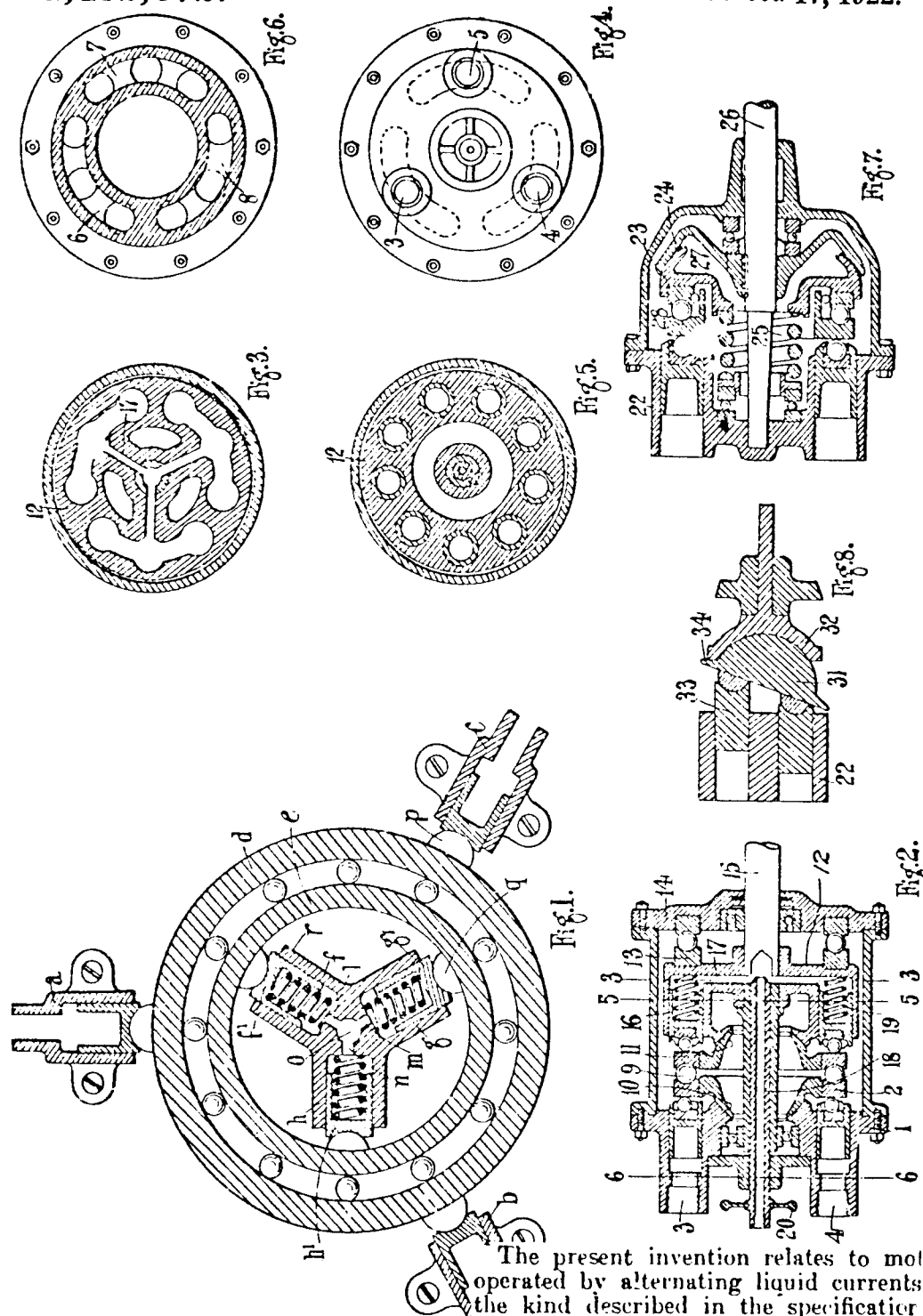
The present invention relates to motors operated by alternating liquid currents of the kind described in the specification of Letters Patent Reissue No. 14738, and has for its object the construction of asynchronous rotary motors actuated by such currents. The term alternating liquid current is defined in specification of Patent No. 1334296.

It will be readily seen that if an eccentric is situated on a shaft, and cylinders and pistons are arranged around the eccentric at angles of 120 degrees apart, and if these pistons are acted on by alternating liquid vibrations also differing in phase by 120 degrees, the effect of the liquid vibrations acting on the pistons is to produce as it were a series of impulses exerted in order about the axis of the shaft acting on the eccentric in a direction parallel with the shaft and exerting a torque if the shaft is made to rotate initially at the synchronous speed.

The working of the motor shown in Figure 7 is as follows:—The rotating field produced by the pulsations of the three phase alternating current in the stator 22 causes the deflection of the plane of the front face of the part 28, which is thus inclined to its normal position at right angles to the axis of the motor, the line of maximum inclination in this plane rotating uniformly about the axis. This inclination is effected against the action of the spring 25, which thus produces the necessary reactance on the members 23, 28. The friction between the members 23 and 24 operates in a similar manner to the liquid friction in the modifications above described, with the result that a torque is produced, acting on the member 24, causing the shaft 26 to rotate. The friction between the parts 23 and 24 should be sufficient to prevent unduly large slip.

In the examples given above, only three phase motors have been described. It will be seen, however, that similar constructions can be adopted for any number of phases.

Further, the stator may be worked by an n-phase line, and the rotor may be an m-phased rotor. The friction device shown in Figure 7 corresponds to an infinite number of phases in the rotor and a limited number of phases in the stator. In order to get a continuous torque, however, three phases at least are necessary. If two phases only were employed, the motor would revolve if initially turned in one direction or the other. The torque, however, would not be constant, but of a pulsating nature. With three or more phases, however, the torque is constant and in one direction. In order to reverse a motor constructed according to this invention, it is only necessary to interchange the phases in the stator by a suitable reversing switch.

In a modified form of motor shown in Figure 8 instead of using a spring as a reactance in order to limit the inclination of the oscillating member, the reactance may be provided by friction between the transmitter 31 and the rotor 32. The limitation of the stroke of the stator pistons 33 is provided for by the flange 34 which bears against the rotor at one point. The necessary friction arises from the pressure of the pistons in the axial direction transmitted through the transmitter to the rotor 32. A thrust bearing may, if desired, be interposed between the pistons 33 and the flange 34 as in the modifications described above.

It will be seen that with motors as above described the maximum torque possible is the torque which is obtained at synchronous speed, that is, when the slip is zero, and it is not possible to obtain the higher torque on starting. The speed of motors according to this invention also cannot exceed synchronous speed equal to that of the generator producing the wave motion in the transmission line.

UNITED STATES PATENT 1,432,673 Patented Oct. 17, 1922.

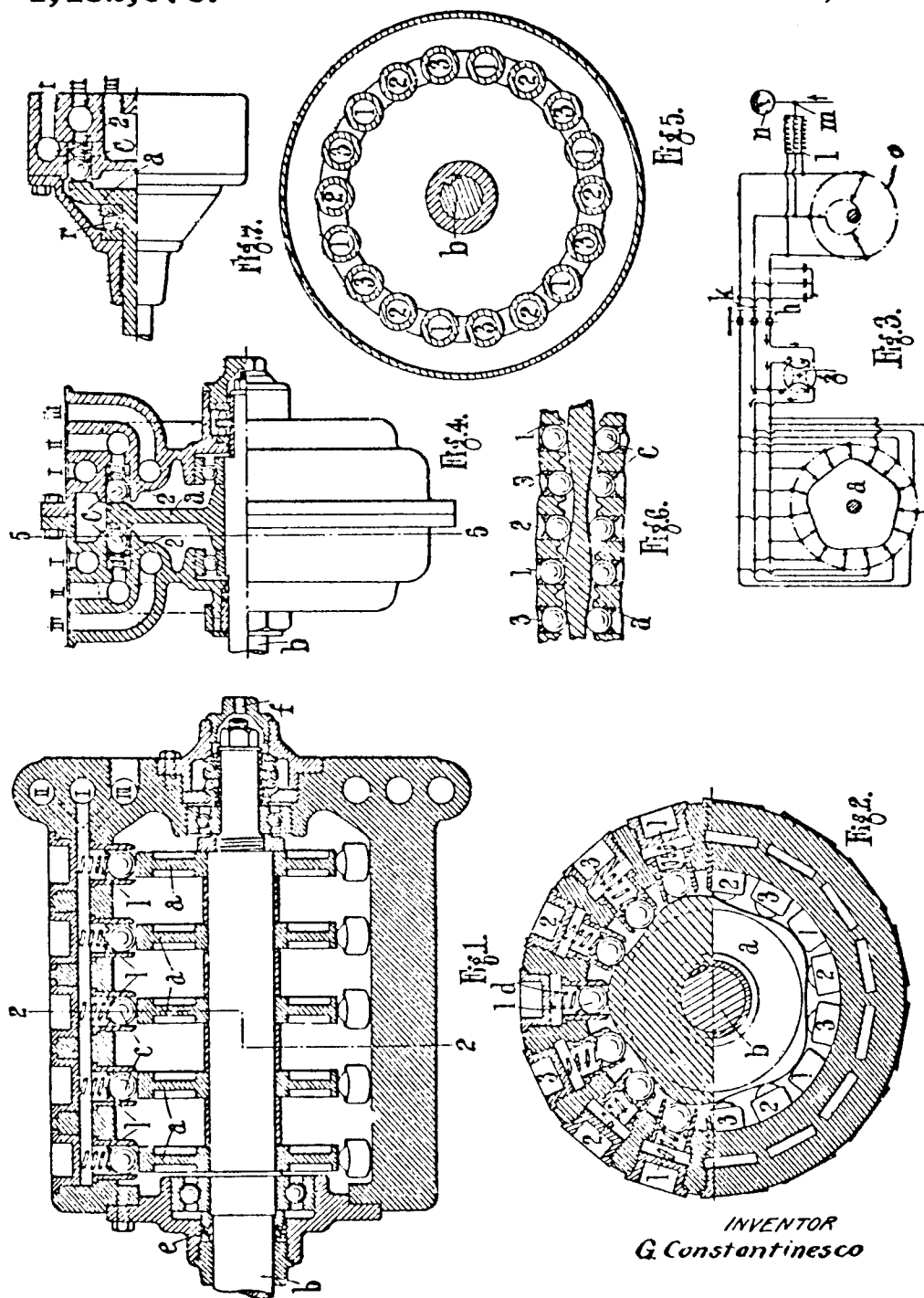GEORGE CONSTANTINESCO, OF WEYBRIDGE, ENGLAND, ASSIGNOR TO WALTER HADDON, OF LONDON, ENGLAND.

G. CONSTANTINESCO.
SYNCHRONOUS ALTERNATING LIQUID CURRENT MOTOR.
APPLICATION FILED AUG. 25, 1921.

1,432,673.

Patented Oct. 17, 1922.

INVENTOR

G. Constantinesco

The present invention relates to alternating liquid current motors and especially to motors for use in wave transmission systems, and has for its object the production of a synchronous rotary motor running at a speed differing from that of the generator, and actuated by a polyphase alternating liquid current. The term alternating liquid current is defined in the specification of Patent No. 1,334,290.

In Letters Patent Reissue No. 14,738 it is shown how energy can be transmitted from one point to another by means of a series of periodic variations of pressure and volume, travelling along one or more liquid columns. For example, if a motor is formed by three cylinders and pistons placed at 120° apart, the pistons differing in phase of motion also by 120°, such a motor will be kept rotating by the pulsations of a three-phase liquid wave transmission line fed by a similar generator. This is the simplest form of synchronous motor.

A motor of the type described would be very difficult to start, and would be incapable of starting against an inertia fixed on the shaft, as the effects of inertia increase considerably with the speed, and would prevent starting where the synchronous speed is high.

The object of the present invention is to obtain a synchronous alternating liquid current motor running at a very much lower speed than the speed of the generator.

The invention consists in a valveless alternating liquid current motor comprising three groups of pistons in cylinders, each group being connected by suitable connections to one of three liquid columns, the group being arranged around the motor in such a manner that the movements of the different groups differ by 120° in phase, while the rotor is so shaped that the pistons reciprocating in contact with it move with a simple harmonic motion as the rotor revolves.

The invention also consists in a valveless polyphase alternating liquid current motor so constructed that the speed of the rotor is different from the speed of the generator.

It will be readily seen that such a machine may either act as a motor or generator according as the power is applied to rotate the shaft or to the movement of the liquid columns acting on the shaft.

The invention further consists in constructing the apparatus in such a manner that the speed of the rotor is a sub-multiple of the speed of the generator.

The invention also consists in the improved motors hereinafter described.

It has been proposed in a gas engine to reduce the speed of rotation of the driven shaft relative to the piston speed by causing the pistons to act through links on inclined surfaces on the inner surface of a ring moving with the driven shaft. It has also been proposed in fluid pressure engines with distributing valves to cause the pistons to act on cam surfaces designed to move the shaft through a part only of a revolution during one complete reciprocation of a piston.

Chapter Six

PATENT PAPERS AND OTHER GOOD LUCK CHARMS

Good luck profiting from a pioneering energy
invention, with the good old patent office
standing in your way protecting you. Several
complete patent papers.

Contents

Fig.1.

Fig.2.

Inventor

Toribio Bellocg

By *Emil Börnelycke*

Attorney

UNITED STATES PATENT OFFICE

TORIBIO BELLOCQ, OF BUENOS AIRES, ARGENTINA

APPARATUS FOR THE EXTRACTION OF LIQUIDS

My invention relates to moving or transporting liquids and especially to extracting or pumping liquids from deep wells or other source of supply in a new manner, its main purpose being directed towards a pumping scheme of very simple and economical construction by which the mechanism at the bottom of the well is reduced to a minimum and the extraction of fluid effected from the ground level substantially irrespective of the depth of the well, and thus when used for water it is not limited to the 25 or 30 foot limit of the usual suction pump for water, and generally the limits usual with pumps for other liquids do not persist. In order that my present invention may be clearly understood and easily carried into practice, a preferred embodiment thereof has been shown in the appended diagrammatic drawings wherein Figure 1 is a vertical section of a well and apparatus and Fig. 2 is a diagram of the curve of the pressure wave to which reference will be made hereinafter.

In the embodiment shown the device consists of a pipe A through which the liquid is withdrawn. The pipe reaches to the bottom of the well, or to the liquid level therein, and is of a suitable length as will be explained. At the bottom of the pipe is a check or retention valve V. The upper end of the pipe A is connected at or about the ground level with a pump or compressor C preferably making rapid reciprocations with a short stroke. The compressor is a valveless pump and is provided with an outlet controlled by an adjustable cock or the like R, through which the pumped liquid may pass from the system. The cock may be opened at the beginning of the operation but may be adjusted to a desirable point during operation.

Before starting the operation of the compressor care must be taken to completely fill the pipe A and the cylinder of the compressor with liquid, carefully excluding substantially all free air and being sure that the piston of the compressor is in the outermost position.

It is well known that energy may be conducted through a column of liquid by setting up a wave motion therein. The waves so set up are comparable to sound waves or waves of electric energy. In order to set up such waves it is necessary to cause alternate areas of high and low pressure in the medium and this may be effected by any suitable known means. I find it convenient to use for this purpose a reciprocating piston. The piston of the compressor C when rapidly reciprocated sets up waves in the liquid in the pipe A by alternately compressing the liquid in the pipe and releasing the pressure especially when the piston has a short stroke. These

waves have a length L equal to $\frac{v}{n}$ in which n is

the number of strokes per second of the piston of the compressor C and v is the speed of the wave per second. When operating in water the speed of the wave may be substantially the speed of sound in the water under the operating conditions.

As may be seen from the diagram in Fig. 2 the wave form includes bulges B^1, B^2, B^3 ... which are associated with corresponding nodes N^1, N^2, N^3 .... When the closed end of the pipe is at a distance from the reciprocating piston equal to any number of half waves, that is at O^1, O^2, O^3 ... or when the pipe is cut off at a distance equal to any odd number of quarter waves, that is at N^1, N^2, N^3 ..., a stationary wave may be set up in the pipe. For the purpose of the present invention it is preferred to arrange the valve V at the end of the pipe and adjust the apparatus in such a way that the valve will be at an odd quarter wave length such as N^1, or N^2 etc., but the purpose can be accomplished possibly less efficiently, by other adjustments.

The maximum variation of pressure accompanied by no variation in flow of the liquid occurs at the points O^1, O^2, O^3 ... whereas at the nodes N^1, N^2, N^3 ... the variation in pressure is zero with the maximum variation in flow of the liquid. By the preferred arrangement of placing the valve V at the point N^1 or N^2 etc. the liquid may enter continuously. The valve V tends to remain always open but it may open and close from time to time during the operation. On the other hand the liquid will flow more or less intermittently from the cock R when it is adjusted to the proper opening. The required

1,780,826

...in the apparatus may be regulated ... an appropriate diameter of pipe and by employing a piston of the proper cross-section, stroke and speed. If required or though it desirable or necessary there may be installed a liquid filled bottle or chamber to act as a capacity or condenser in the manner well known in connection with the transmission of energy by means of waves travelling in liquids.

I have found that one specific appropriate apparatus which will illustrate in a concrete way the present invention may consist of a fluid pipe having an internal diameter of one inch. Such a pipe placed in a well having water at a depth of 20 meters may have arranged at its lower end a valve opening 30 millimeters in diameter seated in which is a ball of approximately 38 millimeters in diameter and held in place by the usual cage which may be adjusted so that the ball can rise from its seat about 20 millimeters. On the surface of the earth the pipe may be led into the cylinder of a compressor of 50 millimeter diameter in which is a piston having a stroke of about 85 millimeters. The piston may be reciprocated at a speed of about 300 revolutions per minute by an electric motor. Leading out from the cylinder of the compressor may be a pipe of one half inch internal diameter in which is placed an adjustable cock or valve. The cock will not be closed but is used merely for adjusting the out flow. The piston will be moved to its outermost position and the cylinder and pipe entirely filled with water, the cock being left open. At this time the ball valve will be closed. On starting the electric motor the ball valve will lift from its seat and may remain open throughout the operation when the cock is properly adjusted, but it may vibrate from its seat opening and closing during the operation. Water will begin to flow from the outlet and by an appropriate adjustment of the cock a continuous operation may be effected and an output of 1,000 liters per hour procured.

While the fundamental theory on which the operation is based may be somewhat in doubt, I believe that the rapid reciprocation of the piston working upon the water in the apparatus produces a series of periodic pressure variations with periodic changes of pressure and volume throughout the liquid column due to the elasticity and compressibility of the liquid. The energy waves so set up travel to the valve V at which point they may be reflected and the transmitted energy is sufficient to open the valve V and lift the column of liquid at the same time drawing in liquid from the well itself. In some systems of energy transmission through liquid there is no substantial flow of the main body of liquid for carrying the energy. I have discovered, however, that apparently the transmission of energy may go through a flowing column of liquid and the transmitted energy may be relied upon to keep the liquid in more or less constant flow.

According to the present invention liquids may be extracted from substantially any depth without using any complicated machinery or mechanism in the well and simply by lowering a pipe of the required length and dimensions duly connected to a simple compressor the latter being at or about the ground level. The valve at the lower end of the pipe will be subject to substantially no wear if the valve is substantially always in its open position during the operation of the compressor. On starting this valve is closed and great care must be taken when filling the pipe and cylinder with liquid to see that substantially no free air remains in the system.

The piston may work either with the cylinder horizontal or with the cylinder vertical or inclined. The pipe through which the liquid flows may be either horizontal or vertical or inclined and it may be curved or straight. All of these arrangements may be referred to as pumps and I use the term pumping as including moving, transporting or conveying in vertical or horizontal or inclined direction.

The term liquids is used to include not only simple liquids but also mixtures of liquids and such mixtures of liquids with gases or solids as are capable of being transported through pipes or pumped.

It is obvious that the device has been shown only as a preferred embodiment and that any other may be used for the same purpose. Apparatus for carrying out the invention may be constructed from mechanisms or devices already known and used for other purposes and the invention is not confined to any specific form of valves or compressors or means of operating them.

I claim:

1. An apparatus for pumping liquids comprising a pipe filled with liquid leading to the liquid supply, a check valve in the end of the pipe in the liquid supply, a compressor cylinder at the other end of the pipe, an open outlet from the cylinder, and a piston in the cylinder and means to cause the piston to alternately compress the liquid in the pipe and release the pressure.

2. An apparatus for pumping liquids comprising a pipe leading to the liquid supply and filled with liquid, a check valve in the pipe within the liquid to be moved, an outlet for the pipe open to the air, and means for alternately compressing the liquid in the pipe and releasing the pressure.

3. Apparatus for pumping liquids comprising a check valve in the liquid supply, a compressor adjacent the point of delivery, a pipe filled with liquid leading from the valve to the compressor, an outlet for the liquid, and means for operating the compressor to

nately compress the liquid in the pipe
and release the pressure to operate the check
valve and move the liquid.

4. Apparatus for pumping liquids com-
prising a check valve in the liquid supply, a
compressor at the point of delivery including
a cylinder and a piston and an outlet, a pipe
filled with liquid extending from the valve to
the compressor, and means for reciprocating
the piston rapidly through a short stroke
whereby the compression of the liquid pro-
duced by the piston is varied.

5. The method of pumping liquids com-
prising alternately compressing a confined
body of liquid in a pipe and releasing the
pressure and causing the pressure variations
to move the liquid toward the compressing
means and permit new liquid to enter the
pipe from a source of supply.

6. The method of pumping liquid compris-
ing placing in the liquid supply a pipe pro-
vided with an outlet near one end and carry-
ing at the other end a check valve in the liquid
supply, filling the pipe with liquid, and alter-
nately compressing the liquid in the pipe and
releasing the pressure to cause the liquid to
flow toward the compressing means near the
outlet and to cause new liquid from the
supply to enter the pipe.

7. The method of pumping liquids in pipes
having outlets comprising repeatedly com-
pressing liquid in the pipe and releasing the
pressure, and causing the pressure variations
to pass through the liquid so as to cause liquid
to enter the pipe and pass through it.

8. Apparatus for pumping liquids com-
prising means for alternately compressing a
body of liquid in a pipe and releasing the
pressure, and an outlet for the pipe, whereby
the variations in compression cause liquid to
enter and flow through the pipe.

9. The method of pumping liquid through
a pipe provided with an outlet near one end
and a check valve at the other end, compris-
ing placing the check valve in the liquid to
be pumped, filling the pipe with liquid and
alternately compressing and releasing the
liquid in the pipe.

In testimony whereof I affix my signature.
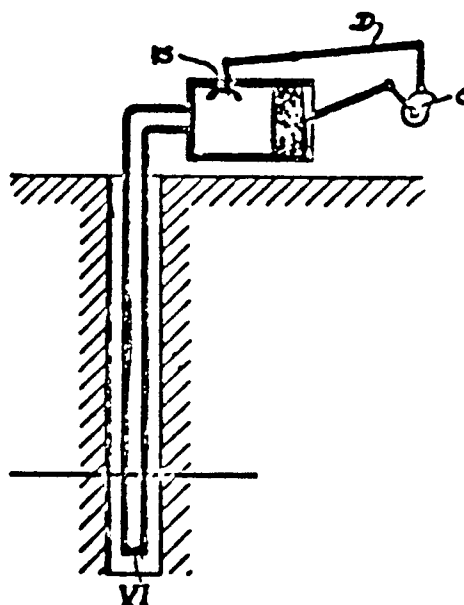
TORIBIO BELLOCQ.

INVENTOR.
Toribio Bellocq
BY
Emil Bönnelycke
ATTORNEY.

Patented Oct. 1, 1929

1,730,337

UNITED STATES PATENT OFFICE

TOEIBIO BELLOCQ, OF BUENOS AIRES, ARGENTINA

PUMP

My invention relates to a new type or scheme of moving or transporting liquids and especially to pumping permitting of the elevation of liquids from substantially any depth without the necessity of situating the machinery at the bottom of the well and includes the employment not only of the energy produced by the waves set up by the rapid reciprocation of a piston but also the extra waves or impulses produced by the opening and closure of a valve in the system. Variations of pressure in the body of liquid in the pump may be employed to effect the pumping and it is more efficient and a larger output is produced if the variation is produced in a plurality of series.

Figure 1 of the accompanying drawing illustrates a vertical section through apparatus incorporating the invention.

The apparatus for carrying out the invention consists of a pipe reaching to the bottom of the well or within the water therein and provided at its lower end with a check valve VI. At or about the ground level the pipe enters the cylinder of a pump or compressor provided with a piston. The cylinder has a single valve VS. In beginning the operation the piston is placed at its outermost position and the pipe and cylinder are completely filled with liquid, care being taken to exclude substantially all free air. The valve VI prevents the liquid running out of the pipe and the valve VS is closed. The piston is then pushed forward by a suitable power and its reciprocation started. After the piston has moved a proper part of its stroke the valve VS is opened and liquid issues therefrom. The valve VI also opens and liquid enters the bottom of the pipe from the well and the continued operation of the device lifts liquid from the well bottom and delivers it through the valve VS which is closed at the proper part of each stroke of the piston at which time the outflow of liquid will be temporarily stopped.

I have thus described the physical operation of the apparatus, while the underlying theory of its operation and the theoretical application of the physical forces involved may not be entirely clear, there will now be set forth a full and clear statement of what is believed to be the explanation of the operation and how the physical forces interact with the apparatus to produce the desired effect.

The apparatus employed involves three parts, namely (1) the apparatus for producing the impulses or waves of force and for producing the opening and closing extra waves or impulses (2) the transmission line or pipe (3) a valve in the lower end of the pipe which may produce in its turn opening and closing extra waves or impulses.

1. The first portion of the apparatus may consist of a compressor of any approved design having a single valve VS diagrammatically illustrated in Fig. 1. The piston of the compressor is rapidly reciprocated preferably through a short stroke so as to produce waves of energy in the liquid column. Initially the piston is moved to its outermost position and the pipe and compressor cylinder filled with liquid. The valve VS is initially closed. The compression of the liquid caused by the inward stroke of the piston initiates a wave movement through the column of liquid. When the movement of the piston has produced the desired pressure, which may be before or at the end of its stroke, the valve VS is suddenly opened. The cooperation and relative timing of the piston and valve may be accomplished in any appropriate way but I prefer to have them mechanically interlocked so that the valve will open at the appropriate moment in the piston stroke. When this valve opens it suddenly, by the variation of pressure, transforms the piston wave into an opening extra impulse or wave in the liquid column. Advantage may be taken also of the extra wave caused by the closure of the valve but the closure extra waves are of lesser effect than the opening extra waves. Valve VS being closed when the piston enters the cylinder a certain pressure is produced to set up a wave in the liquid column. When the valve VS opens the opening sets up an extra or supplemental wave impulse which like the piston wave will travel through the whole length of the liquid in the pipe to the lower valve VI. This extra or auxiliary wave

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impulse may be similar also to that pro-
duced in water rams. The water ram, how-
ever, takes advantage of the closing extra
wave rather than the extra wave produced
by opening. In my system this extra wave
when working with the valve VS open to the
air is probably one of much volume and
slight pressure. This wave and extra wave
cause the liquid to proceed from the well by
10 valve VI and carry it through the pipe and
and drive it through valve VS which is open.
It is necessary to calculate the necessary pres-
sure and velocity of the wave for the
length and diameter of the pipe employed as
15 a guide in altering or adjusting, in each case,
the diameter, stroke and frequency of the
piston. As is well known in systems trans-
mitting energy by wave through columns or
pipes of liquid the pressure produced in a
20 tube or pipe of a given diameter may be varied
or controlled by providing in communi-
cation with the pipe a further container filled
with the same liquid which is being pumped
to act as a capacity or condenser. In order
25 to set up such waves it is necessary to cause
alternate areas of high and low pressure in
the medium and this may be effected by any
suitable known means. I find it convenient
to use for this purpose a reciprocating piston
30 and valve as indicated.

2. The second portion of the apparatus con-
sists merely of a suitable pipe which brings
up the liquid and, through the flowing
stream, transmits the energy or waves from
35 the piston and the upper valve VS to the low-
er valve VI it being necessary to calculate
the section of the pipe in accordance with
the pressure and the volume of the liquid to
be obtained or extracted from the well. Since
40 energy-bearing wave-currents in liquid have
a certain velocity, the frequency of the pis-
ton, must be calculated in order that the
wave produced should conform with the
length of the pipe, it being possible to work
45 likewise with the harmonics of the wave
and also to work when the pipe length cor-
responds with odd or even fourths of such
wave length. This is preferred but the pur-
pose can be accomplished, possibly with less
50 efficiency, with other adjustments.

3. The third portion of the apparatus
consists of the lower valve VI which may
serve three purposes, (a) it serves as a non-
return valve so as to permit the pipe being
55 filled up before starting; (b) it causes the
liquid to move in one direction only avoid-
ing the return thereof into the well; and (c)
it may be that it also serves as a wave or im-
pulse transformer like the upper valve VS
60 producing by its movement an extra wave
or impulse. Thus the pipe will draw in a
great quantity of liquid under low pressure
being the inverse of the piston which pro-
duces a wave or impulse of high pressure and
65 little volume.

At first sight it might seem that if the pis-
ton is caused to enter the cylinder when the
valve VS is closed the apparatus would burst.
This is not the case, however, since the ca-
pacity for compression and the elasticity of 70
the liquid being pumped, when known, serve
to allow the stroke of the piston and the pres-
sure obtained to be calculated and the ap-
paratus to be operated in such a way as not
to exceed the limit of resistance of the ap-
paratus before the opening of the valve. It
will be remembered that the impulses and
extra impulses of energy in the wave form
are possible solely because the liquids worked
upon are compressible and elastic which per- 80
mits of their working in a resilient manner.

The operation of the apparatus is as fol-
lows. The piston is withdrawn from the cyl-
inder to the maximum extent possible and
the cylinder and pipe are filled up substan- 85
tially completely with liquid taking care
that substantially no free air be left inside.
The valve VS is closed and the piston is
pushed inwardly vigorously causing a com-
pression of the liquid and initiating an en- 90
ergy carrying wave which moves through
the column of liquid. As soon as the piston
has entered sufficiently to produce the desired
pressure the valve VS is suddenly opened.
This abrupt opening of the valve VS per- 95
mits escape of liquid and suddenly changes
the pressure thus producing an opening extra
wave which will travel through the whole
length of the pipe. The waves produced by
the piston and by the valve VS both carry 100
energy to the valve VI which will be opened.
The system is more economical and more ef-
ficient than one which employs for the pump-
ing and lifting of the liquid only the energy
transmitted by the waves set up by the piston 105
action. If the opening of the valve VI is
abrupt it may transform the extra wave into
a wave of small pressure but great volume.
Since the valve VI does not permit the liquid
to flow downwards an upward flow will occur, 110
that is to say, the energy transmitted by the
two waves will not only open the valve VI
but will lift the liquid in the pipe and draw
from the well liquid past the valve VI and
upwards through the pipe from which it will 115
discharge through the open valve VS. Op-
eration then may become substantially con-
tinuous the piston being rapidly reciprocated
and the valve VS operated in harmony there-
with being always closed at the proper part 120
of the piston stroke. It might be best to ar-
range the shaft moving the piston so that it
would also govern the valve VS. Thus the
work might be done in a completely auto-
matic manner. Thus a cam C may be 125
mounted on the drive shaft and engage mech-
anism D to operate the valve VS at the proper
predetermined point in the stroke of the
piston. Any other suitable means for asso-
ciating the operation of the piston and 130

... valve may be employed. The time of opening and closing the valve VS and its size may be adjusted to give the maximum output of liquid with the minimum expense of energy to operate the piston. The apparatus expels during each stroke of the piston a volume of liquid several times greater than the volume displaced by the piston. In practice it is possible to expel during each stroke of the piston a volume of liquid about seventeen times as large as the volume displaced by the piston and for this reason the stroke of the piston may be very short or the volume displaced at each stroke of the piston may be small.

I have found that one specific appropriate apparatus which will illustrate in a concrete way the present invention may consist of a fluid pipe having an internal diameter of one inch. Such a pipe placed in a well having water at a depth of 20 meters may have arranged at its lower end a valve opening 30 millimeters in diameter seated in which is a ball of approximately 38 millimeters in diameter held in place by the usual cage which may be adjusted so that the ball can rise from its seat about 20 millimeters. On the surface of the earth the pipe may be led into the cylinder of a compressor of 50 millimeters diameter in which is a piston having a stroke of about 30 millimeters. The piston may be reciprocated at a speed of about 180 revolutions per minute by a suitable electric motor. In the cylinder of the compressor may be a valve having a diameter of about 30 millimeters and adjusted so as to have a movement of from 5 to 7 millimeters. The piston will be moved to its outermost position and the cylinder and pipe entirely filled with water. The ball valve rests by gravity in its closed position and the valve in the cylinder is closed. The electric motor will be started and at the proper time in the stroke of the piston the valve in the cylinder will be opened. The ball valve will open and water will begin to flow from the piston valve with an output of about 4,000 or 5,000 liters per hour.

While the fundamental theory on which the operation is based may be somewhat in doubt, I have endeavored to set out herein what I believe is the true principle but my invention is not to be so limited. In order to set up such waves as are here involved it is necessary to produce variations in compression in the liquid and although a compressor is illustrated for such purpose it will be understood that the invention is not so limited but extends to any suitable or known means for producing such effect.

This system permits of working at any desired depth without being compelled to arrange the machinery within the well. provided the necessary pressure has been well calculated. It is possible that advantageous-

ly, the work is done under a considerable pressure in order to use, same as in electricity, the transmission of high voltages over long distances with favorable output. This system also permits of working with a piston of reduced dimensions as, taking advantage of the transforming effect of the wave or impulse, a piston of a given displacement, under a given pressure, would be able to elevate at each stroke a liquid volume several times greater than the same displacement but under a pressure several times lower.

This system would seem to be contrary to the laws of gravity which does not permit of liquid being elevated or drawn up from a depth greater than the length of a column of the same liquid counter-balancing the atmospheric pressure; however, in fact there is employed a force in wave form which travels throughout the length of the pipe and arrives at the lower valve VI. This force operates at this valve in the same manner as if there were a piston at this point.

The present system would seem also to be contrary to the law which does not permit a piston of a given displacement to obtain at each stroke a volume of liquid greater than such displacement; but it will be apparent that a piston of a given displacement, under a given pressure, may obtain at each stroke a liquid volume several times greater than the volume of displacement of such piston, but under a pressure several times less.

The piston may work either with the cylinder horizontal or with the cylinder vertical or inclined. The pipe through which the liquid flows may be either horizontal or vertical or inclined and it may be curved or straight. All of these arrangements may be referred to as pumps and I use the term pumping as including moving, transporting or conveying in vertical or horizontal or inclined direction.

The term liquids is used to include not only simple liquids but also mixtures of liquids and such mixtures of liquids with gases or solids as are capable of being transported through pipes or pumped.

It is obvious that the device has been shown only as a preferred embodiment and that any other may be used for the same purpose. Apparatus for carrying out the invention may be constructed from mechanisms or devices already known and used for other purposes and the invention is not confined to any specific form of valves or compressors or means of operating them.

Having thus fully described and ascertained my said invention, and the manner in which the same is to be performed and carried into practice. I declare that what I claim and desire to secure by Letters Patent is:—

1. Apparatus for pumping liquids comprising a pipe filled with liquid leading to the liquid supply, a check valve in the end

... (... liquid supply, a compressor
... (... and ... the pipe, an out-
1 ... for the liquid, a piston in the cylinder,
... to ... the piston to repeatedly com-
... the liquid in the pipe, a valve in the out-
let and means for opening the outlet valve at
a predetermined point in each stroke of the
piston.

2. Apparatus for pumping liquids com-
prising a pipe leading to the liquid supply
and filled with liquid, a check valve in the
pipe within the liquid to be moved, an outlet
for the liquid, means for compressing the liq-
uid in the pipe, and separate means for sud-
denly releasing the pressure.

3. Apparatus for pumping liquids compris-
ing a check valve in the liquid supply, a com-
pressor adjacent the point of delivery, a pipe
filled with liquid leading from the valve to
the compressor, an outlet for the liquid,
means for operating the compressor to com-
press the liquid in the pipe, and separate
means to suddenly release the pressure, to
operate the check valve and move the liquid.

4. The method of pumping liquids com-
prising placing in the liquid supply a pipe
provided with an outlet near one end con-
trolled by a valve and carrying at the other
end a check valve in the liquid supply, filling
the pipe with liquid, compressing the liquid
in the pipe, and operating the valve con-
trolling the outlet to suddenly release the
pressure to cause the liquid to flow toward
the compressing means near the outlet, and to
cause new liquid from the supply to enter
the pipe.

5. The method of pumping liquid through
a pipe provided with a controlled outlet near
one end and a check valve at the other end,
comprising placing the check valve in the liq-
uid to be pumped, filling the pipe with the
liquid, and repeatedly compressing the liquid
in the pipe and operating the outlet control-
ling means to suddenly release the compres-
sion.

6. Apparatus for pumping liquids com-
prising a pipe leading to the liquid supply
and filled with liquid, a check valve in the
pipe within the liquid supply, an outlet for
the liquid, and means to set up a contempora-
neous plurality of series of compression
waves in the liquid in the pipe to operate the
check valve and move the liquid.

7. The method of pumping liquids in pipes
comprising repeatedly compressing the liq-
uid to cause a series of impulses of energy
in the form of compression waves to pass
through the liquid and repeatedly suddenly
relieving the compression of the liquid to
cause another series of impulses of energy
in the form of compression waves to pass
through the liquid to cause liquid to pass
through the system.

8. Apparatus for pumping liquids com-
prising a pipe leading to the liquid supply

and filled with liquid, a check valve in the
pipe in the liquid supply, a compressor cyl-
inder at the other end of the pipe, a valve in
the cylinder, a piston in the cylinder and
means for operating the piston and the valve
in the cylinder to set up a plurality of series
of compression waves in the liquid in the pipe
to operate the check valve and pump the liq-
uid.

9. The method of pumping liquid through
a pipe provided with a controlled outlet near
one end and a check valve at the other end,
comprising placing the check valve in the
liquid to be pumped, filling the pipe with
the liquid, and applying energy to the liquid
in the pipe in a contemporaneous plurality
of series of impulses in the form of compres-
sion waves at a point toward which flow oc-
curs.

10. Apparatus for pumping liquid com-
prising means for alternately compressing a
body of liquid in a pipe, separate means for
alternately releasing the pressure, and an
outlet for the pipe, whereby the variations
in compression cause the liquid to enter and
flow through the pipe.

In testimony whereof I affix my signature.

TORIBIO BELLOCQ.

Fig. 3. Fig. 4. Fig. 5. Fig. 6.

Fig. 7. Fig. 8.

Fig. 1.

Fig. 2.

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Band

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PUMPING

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Fig.18.

Fig.19.

Fig.20.

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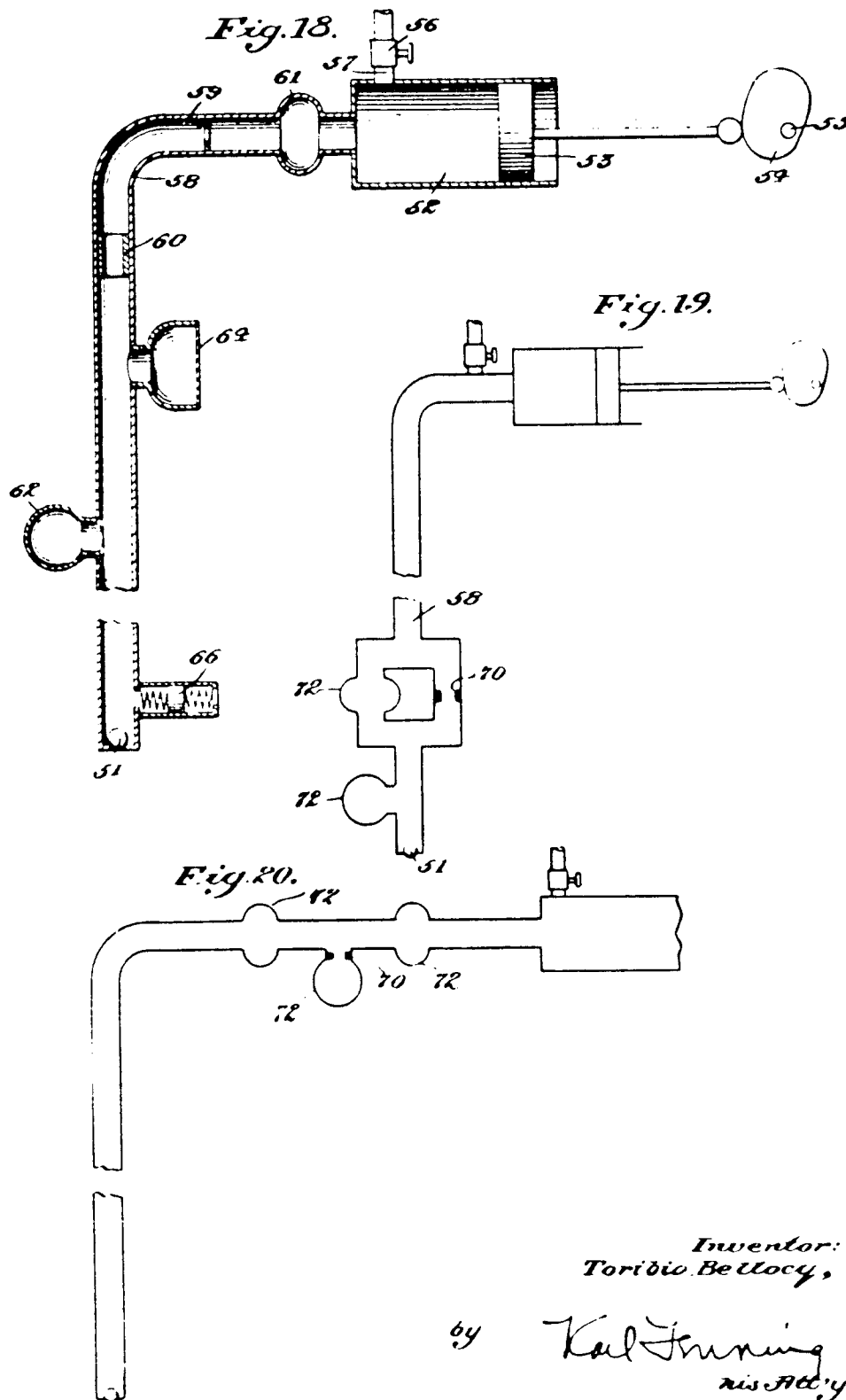
Patented Jan. 2, 1934   **1,941,593**

UNITED STATES PATENT OFFICE

1,941,593

PUMPING

Toribio Bellocq, Buenos Aires, Argentina

Application September 30, 1929
Serial No. 396,297

21 Claims. (Cl. 103—1)

The invention relates to pumping liquid especially by that method by which the energy for moving the liquid is transmitted through the liquid itself by means of compression waves or
5 variations of compression and volume moving through the liquid whereby liquids may be extracted from substantially any depth without complicated mechanism in the well

Pumps of this kind are described in Patent
10 1,730,336 and 1,730,337 issued October 1, 1929, the applications for which were pending in the Patent Office when the present application was filed.

The present invention involves the discovery
15 that an improved pumping effect may be accomplished by modifying the relative size and arrangement of the various elements of the pumping system and by adding to or inserting therein certain auxiliary devices. These are re-
20 ferred to herein as filters and may be made up of inertias, capacities, resistances, leakages or any of them and may be arranged in series, in shunt or in derivation to the main liquid conveying pipe of the pumping system.

25 Compression waves moving in liquid are to a very considerable extent controlled by or operate in accordance with substantially the same laws as those governing alternating current electricity. The curves of pressure and flow of such waves
30 are analogous to the voltage and amperage curves of electric current in that the difference in phase may determine the value of the wave. Inertia, capacity, resistance, or friction and leakage in a liquid system correspond more or less to in-
35 duction, capacity, resistance, and losses respectively in electricity.

Variations in capacity or in leakage or in resistance or in inertia in the system effect changes therein including varying phase differ-
40 ences between pressure and flow of the impulses in the liquid. In an ordinary line which has its capacity, inertia, resistance and leakage more or less uniformly distributed throughout the length of the apparatus the efficiency of the line
45 and the quantity of liquid which is to be pumped with such efficiency may be determined. Often, however, it may be desired to change the conditions of such a line to adapt it to a given speed, given efficiency or a given volume of pumped
50 liquid. There may be produced an artificial line whose capacity, inertia, resistance and leakage will be the combination of the natural capacity, inertia, resistance and leakage with added capacity, inertia, resistance and leakage.

55 Inertia, as employed herein, refers to an ele-

ment in or inserted in the system for reducing the passageway at one or more points and or decreasing the elasticity of the liquid.

Capacity, as employed herein, refers to an element in or inserted in the system for increasing 60 the passageway at one or more points and or increasing the elasticity of the liquid.

Leakage, as employed herein, refers to liquid leaving the system whether at the main outlet for the pumped liquid or at other points in the 65 system some of which may be accidental, unavoidable and incalculable. The entrance of liquid into the system may be considered as negative leakage.

Resistance, as employed herein, is the retard- 70 ing effect of the system on the wave movement.

Friction, as employed herein, is the resistance caused by contact of the liquid with the pipe or within the liquid.

Filter, as employed herein, refers to assemblage 75 of inertias, capacities, resistances and leakages, or one or more of them, and this is referred to by the term "wave filter" used in the claims.

A filter may be said to be arranged in series when it is in such a portion of the system that 80 a wave goes directly through the filter and passes on to another portion of the system. A filter may be said to be in shunt when the wave takes a divided path going through a plurality of elements of the filter. A filter may be said to be 85 in derivation when the wave enters it from the main path of the wave and returns again to that path.

In the accompanying drawings Figure 1 is a diagrammatic illustration of one form the pump- 90 ing apparatus may take. Fig. 2 is a diagrammatic illustration of another form the apparatus may take. Figs. 3 and 4 are longitudinal sections of pipes provided with inertias. Figs. 5, 6, 7 and 8 are longitudinal sections of pipes 95 provided with capacities. Figs. 9, 10 and 11 are diagrammatic illustrations of low pass electric filters. Figs. 9a, 10a and 11a are diagrammatic illustrations of low pass acoustic filters applied to liquid systems. Figs. 12, 13 and 14 are dia- 100 grammatic illustrations of high pass electric filters. Figs. 12a, 13a and 14a are diagrammatic illustrations of high pass acoustic filters applied to liquid systems. Figs. 15, 16 and 17 are diagrammatic illustrations of band pass electric 105 filters. Figs. 15a, 16a and 17a are diagrammatic illustrations of band pass acoustic filters applied to liquid systems.

Fig. 18 is a diagrammatic illustration of a pumping apparatus such as shown in Fig. 1 to 110

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which is applied the devices illustrated in Figs. 3, 4, 5, 6, 7 and 8. Fig. 19 is a diagrammatic illustration of a pumping apparatus such as shown in Fig. 2 to which is applied the apparatus illustrated in Fig. 11a. Fig. 20 is a pumping apparatus such as is illustrated in Fig. 1 to which is applied the device illustrated in Fig. 13a.

The pumping system in general is illustrated as including a pipe 50 provided with a check valve 51 at its lower end intended to be inserted in the well or other source of supply of liquid to be pumped. At the other end of the pipe is shown a compression chamber or cylinder 52 in which moves a piston 53 controlled by a cam 54 on a suitably operated shaft 55. There is an outlet cock or valve 56 of any suitable type through which the liquid is pumped here shown in an outlet pipe 57. In Fig. 1 the outlet is shown leading directly from the compression chamber or cylinder 52 while in Fig. 2 it is shown. as directly connected to the pipe 50 so that the outgoing liquid will not pass through the compression chamber or cylinder. The cock or valve 56 may be open at all times during operation or it may be opened and closed at appropriate times during the operation either manually or automatically.

In Fig. 3 a pipe 58 is shown provided with a narrow annular obstruction 59 which acts as an inertia for the current of waves passing through liquid in the pipe In Fig. 4 there is shown at 58 a similar inertia 60 which takes the form of an elongated sleeve and so has a different value from the inertia shown in Fig. 3. In Fig. 5 is shown a pipe 58 provided with rigid protuberances of which act as a capacity in series with the pipe. In Fig. 6 is shown a pipe 58 which is connected to a closed rigid chamber 62 which when filled with liquid acts as a capacity in derivation. In Fig. 7 is shown a pipe 58 connected with a chamber 63 closed at its outer end by a diaphragm 64. When the chamber 63 is filled with liquid it acts as a capacity in derivation. In Fig. 8 is shown a pipe 58 from which leads a pipe 65 in which is a snugly fitting piston 66 movable against springs 67 and 68. The resiliency of the springs takes the place of liquid resiliency and acts as a capacity in derivation to the pipe 58. These are illustrative only and other forms of inertia and capacity may be employed.

The pipe through which liquid is to be pumped may be horizontal, vertical or inclined or bent. If there is a bend in the pipe the relation between the parts on each side of the bend tends to produce an harmonic of the principal wave and in order to work most efficiently this harmonic should preferably have a node in the elbow at the bend. The elbow thus acts as an inertia.

The entrance or the exit of the liquid pumped may also tend to produce an harmonic four times as long as the length of the liquid which passes through the pipe at each stroke of the compressing device. It is desirable to have this harmonic the same as the harmonic produced by the proportion between the portions of a bent line, or at least an harmonic thereof. The flowing of the liquid through the inlet or the outlet has somewhat the effect of an inertia. The change in size between the pipe carrying the liquid and the cylinder of the compressor at their point of connection has somewhat the same effect as an inertia. The small chamber generally employed at the outlet cock or valve between the compressor piston and the pipe line and likewise the cylinder itself each have somewhat the same effect as a capacity. This chamber may be omitted and the cylinder alone be referred to as the compression chamber.

There are several elements of the apparatus which may be adjusted to change or vary the efficiency of operation including: (1) the size of the compression chamber may be varied; (2) the relative size of the connection between the compression chamber and the pipe may be varied; (3) the cross-section of the pipe through which the liquid is pumped may be varied; (4) the speed or timing of the piston may be varied; (5) the size or cross-section of the piston or its length of stroke may be varied (6) the size or opening of the check valve through which liquid enters the system may be varied; or (7) the size and suddenness of the opening of the outlet may be varied. In order to procure proper and appropriate adjustments or regulation of the system any or all of the various elements may be appropriately and correspondingly varied. The quantitative effect of variations in the different elements of the apparatus is not the same.

A difference in operation is produced when the outlet is in the compression chamber from that produced when the outlet is on the pipe. In the first arrangement increasing the size or opening of the check valve or in the second arrangement decreasing the size or the opening of the check valve effects a variation in the same direction as (1) increasing the size of the compression chamber (2) decreasing the relative size of the connection between the chamber and the pipe (3) decreasing the cross-section of the pipe through which the liquid is pumped (4) increasing the speed or decreasing the timing of the piston (5) increasing the size or cross-section of the piston or its length of stroke (6) increasing the size of opening of the outlet. This indicates the direction of change to be made to compensate for any change in the apparatus. If the outlet on the pipe is removed farther from the connection between the pipe and the compression chamber or if inertia associated with the outlet is moved farther from the connection between the pipe and compression chamber the effect is of the same character as would be an enlargement of the compression chamber. It is generally desirable, however, to put the outlet the inertia and the connection between the pipe and the compression chamber as close together as possible because when they are separated one from another there is no longer merely the effect of a chamber assembled at one place but the effect of a chamber like a piece of pipe with different inductions in each extremity. With such an arrangement it is more difficult to calculate the exact value of such a chamber. Sometimes, however it is found desirable to use such an extended chamber despite the difficulty in calculating its characteristics.

It may happen that when the pipe is very long the wave will be deformed as it proceeds through the liquid. It may then be desirable to put additional or new capacities, inertias, resistance or leakage in one or several parts of the apparatus to prevent this deformation of the current. Somewhat similarly in telegraphic and telephonic lines traveling great distances means are provided to prevent deformation of the current such as are provided by the system of Puppin or others.

It may be desirable to choose a variation in

wave of such a character that the liquid will vibrate with the natural vibration produced by gravity. For example a compressor may be so operated as to cause an artificial acceleration during its stroke corresponding to the natural acceleration produced by gravity on the liquid freely falling in the system. When this natural vibration is not convenient for the quantity of liquid it is desired to pump the constants of the line may be appropriately changed to produce the desired effect.

When the pipe is large enough or the quantity of the liquid pumped is small in relation to the size of the pipe, the resistance will be small and for practical purposes may be neglected. It is desirable that the leakage in the system, be reduced to a minimum so that the only value of leakage to be considered may be that produced by the liquid pumped through the outlet. Entrance of liquid into the system may be considered as negative leakage.

The compression waves in the liquid of the pumping system are somewhat analogous to sound waves. Therefore. elements which modify these waves in the liquid of the pump may for convenience be referred to as acoustic elements and it is to be understood that when the term acoustic or hydraulic is employed herein it relates to an element modifying the compression waves in the liquid more or less in accordance with the laws of sound waves in the liquid. This may be a convenient form of expression and it may aid in understanding the present invention to bear in mind the analogy between the compression waves in the liquid in the pumping system and sound waves.

Acoustic inertia or self induction may be an apparatus having only inertia which may be formed for instance by a reduction of a section of the pipe. Likewise acoustic capacity may be a chamber communicating with the pipe and filled with the liquid. Acoustic inertias. capacities. resistances and leakages may be combined to form acoustic filters analogous to electric filters and their effect on the compression waves in the pumping system may be analogous to their effect on sound waves. As in electricity such acoustic filters in the pumping system may be referred to as low pass filters. high pass filters and band pass filters. The low pass filters may let pass or produce vibrations of a frequency lower than a certain speed or may so convert other vibrations received. The high pass filters may let pass or may produce vibrations of a frequency higher than a certain speed or may so convert other vibrations received. The band pass filters may let pass or may produce vibrations of a frequency between two certain speeds. or may so convert other vibrations received. All of these filters may stop or not let pass other vibrations. Acoustic filters may be arranged in accordance with the same laws as electric filters. It may be easier to make filters occupying a very short space in relation to the wave length. It is possible. however. to employ other longer filters but the exact determination of their effect may be more difficult.

The analogies between electric filters and acoustic filters exist not only in words but they are true physical analogies. The phenomena of the propagation of an electric current and of sound waves and of compression waves in liquid are controlled by the same laws. In dealing with these waves the combination of acoustic inertia. capacities, resistance and leakages ac-

complish similar results as are accomplished by combinations of similar elements in electric circuits. In order to facilitate determining the effect of a filter it is desirable that the two extremities of the filter be of the same value. It is possible, however, to employ filters having extremities of different values. In such an arrangement the difference in the two extremities may produce an effect of itself. The ideal filter is one which without substantial loss of energy will let pass the frequency which it is desired to employ in the apparatus and at the same time stop other frequencies. Generally filters of this character cannot be completely realized in practice. but it is desirable to employ filters approaching this ideal as nearly as possible. A general filter may be employed or several filters may be employed in a single system being associated or combined with similar or different filters.

Generally electric circuits employ two wires or lines and the induction. capacity. resistance and leakage may be installed in one or both or between them in series. derivation. or in shunt. In liquid systems. especially pumping systems. usually there is but a single line or pipe but the inertia. capacity, resistance and leakage may be placed in series or in shunt on the line or in derivation on the line in which case the effect is as if the element in derivation communicated at one side with the line and at the other side with a ground analogous to the grounding of an electrical device.

The effect of filters put in derivation may be varied. for example by putting a capacity in derivation made not of a closed chamber filled with the same liquid but of a closed chamber filled with another liquid of different density or elasticity. separated by a membrane from the other liquid or by a chamber filled by the same liquid but closed by a membrane which separates the liquid from the air. The capacity thus is to be considered as not between the line and the ground but between the line and another artificial ground. The natural vibration of the liquid will be different in the different cases. This chamber filled with the different liquid or provided with a membrane may be replaced by a cylinder having a floating piston maintained by springs which make the piston work like a membrane. The introduction of any of these different apparatus having vibration characteristics different from the natural vibrations of the line has the effect of changing the constants of the line and may be employed in a manner similar to the more usual type of filters. Any other suitable form of capacity. inertia. resistance or leakage may be employed.

For installations operated under substantially constant conditions a filter of exact characteristics may be employed. but for other installations less exact filters may be employed.

In Figs. 9. 10 and 11 are shown examples of characteristic electrical low pass filters In Figs. 9a. 10a and 11a are shown similar characteristic low pass acoustic filters applied to liquid systems. The arrangement in Fig. 9a corresponds to that in Fig. 9; the arrangement in Fig. 10a corresponds to that in Fig. 10. while that in Fig. 11a corresponds with that in Fig. 11. In each instance the electrical inertias 69 are replaced by acoustic inertias 70 while the electric capacities 71 are replaced by acoustic capacities 72. Figs. 12. 13 and 14 illustrate types of electric high pass filters and Figs. 12a. 13a and 14a illustrate

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types of acoustic high pass filters corresponding respectively to the electric filters illustrated in Figs. 12, 13 and 14. Figs. 15, 16, and 17 illustrate diagrammatically electric band pass filters and Figs. 15a, 16a and 17a illustrate characteristic acoustic band pass filters applied to liquid systems corresponding respectively to the filters illustrated in Figs. 15, 16 and 17. In all of these figures the electrical inertias 69 correspond to the acoustic inertias 70 and the electric capacities 71 correspond to the acoustic capacities 72. The filter arrangements here illustrated are selected as types only. These and other appropriate electric filters may be followed with like effect and the corresponding acoustic filters inserted at appropriate points in liquid systems with corresponding results and the term filter is used to include all such devices as rectify, transform, alter, or modulate the currents of the compression waves set up in the liquid in the pumping system.

In Fig. 18 is shown a simple pumping system such as shown in Fig. 1 but modified by being associated with the filters or wave modifying devices illustrated in Figs. 3 to 8 inclusive. The capacities 61, 62, 64 and that having the piston 66 are associated with inertias 59 and 60. As illustrated the inertia 59 and the capacity 61 are shown relatively near to the pump cylinder 52 and the other wave modifying devices are distributed throughout the line 66 being very near to the inlet valve 51. 59, 60 and 61 are in series while 62, 64 and 66 are in derivation. This specific arrangement is not essential nor is it essential that all of these devices be incorporated in a single system. In general a single device may be sufficient. For instance the inertia 59 might be employed and the devices 60, 61, 62, 64 and 66 omitted or any two or more of them might be omitted. Likewise the particular position of these various devices in the system is not essential. For instance the device 66 which is shown as near the check valve 51 might be installed where the device 61 is illustrated near the pump cylinder 52 or any other desired arrangement and location of any or all of these devices may be made. Instead of assembling in a single system a plurality of different wave modifying devices as illustrated in Fig. 18 a plurality of similar devices might be employed when more than one is desired and the location of all of the devices is interchangeable. When apparatus such as is illustrated in Fig. 1 is operated the wave produced in the liquid will have certain characteristics and for the conditions of operation it may be that that wave is satisfactory and efficient. It may be, however, that for the conditions under which the apparatus is operating the wave produced by apparatus such as illustrated in Fig. 1 will not have the desired characteristics and may not be effectively efficient to produce the desired pumping effect. By adding to the apparatus shown in Fig. 1 any one or more of the devices illustrated in Figs. 3 to 17 the characteristic of the wave may be modified so as to produce the desired effective efficient result. Thus the wave set up in such an apparatus as Fig. 18 will have characteristics different from the wave set up in such an apparatus as Fig. 1 and the addition or removal of any one of the impedance or capacity devices illustrated in Fig. 18 will correspondingly modify the wave.

In Fig. 19 is shown assembled in such a pump as is shown in Fig. 2 a filter such as illustrated in Fig. 11a and in Fig. 20 such a filter as illus-

trated in Fig. 13a is illustrated in connection with such a pump as shown in Fig. 1. As indicated, when the arrangement is applied to a pumping system there may be present only one pipe line the other pipe being omitted and replaced by an artificial ground similarly to the arrangement by which a two wire electric system may be employed with only one wire and a ground. In the pumping system the effect of a ground may be procured by closing the connection to the omitted pipe. Likewise the filters illustrated in Figs. 9a, 10a, 12a, 14a, 15a, 16a and 17a or any grouping or combinations of them or other filters may be assembled into a single apparatus. The arrangement illustrated in Fig. 19 is in part a shunt arrangement and, incorporating a low-pass filter, will modify the waves in the pumping system and allow only those waves having frequencies lower than a certain desired speed or it may convert to such speed other vibrations in the system. Similarly the filter associated with the pumping system in Fig. 20 being a highpass filter will modify the waves in the pumping system and allow only those waves having frequencies higher than a certain desired speed or it may convert to such speed other vibrations in the system.

The devices shown are only preferred embodiments of the invention, but any other suitable devices may be used for the same purposes.

The weight of the check valve or the strength of springs sometimes controlling it which change the character of its opening change the value of the inertia produced by its opening. The check valve being inertia and so a filter element may be omitted and the other elements of the apparatus adjusted accordingly. When more than one pump is in the pipe line each pump may act as check valve or inlet for the succeeding pump.

Variations in the speed of the piston during a stroke are of importance. When the piston is moved by a crank shaft the speed increases from zero to maximum speed during the first half of the time of the entrance of the piston (that is, the first quarter of a complete cycle) and produces an acceleration in the lifting of the liquid. In the second half of the time of entrance of the piston (that is, the second quarter of a complete cycle) the speed of the piston decelerates going from its high speed to zero speed. Thus the liquid tends to be lifted with more strength when the piston is entering during the first half of its forward stroke and tends, because of the deceleration, to be lifted with less strength in each unit of time when the piston is entering during the second half of its forward stroke. In general under these conditions it is better to open the outlet valve when or before the piston reaches the half point of the inward stroke. Sometimes it may be better to open the valve at the end of the entrance stroke of the piston or somewhat before. When a proper cam is employed to operate the piston, the piston speed increases throughout the entire advance movement so the same effect may sometimes be produced by a cam which gives only one-half the length of movement to the piston as would be given by a corresponding crank. When such a cam is used only only-half as much liquid may be forced out of the piston cylinder as with a crank and hence at each stroke less liquid need go into the cylinder to keep it full in order to get as much liquid output from the apparatus. With the most efficient adjustment of the apparatus, during the acceleration of the piston liquid is lifted, that

is to say, the liquid may be moving from the check valve to the compressor. If the valve is opened at this moment the liquid which is already moving upward, will tend to be lifted with more efficiency since it is not obliged to change its direction.

The suddenness of opening the outlet being the principal element in the transformation of the compression waves should be especially considered and arranged to cooperate with the rest of the system.

In certain cases it may be desired to produce a certain pressure in the apparatus at the time the outlet is opened as in this connection it seems that the liquid pumped going out with a certain pressure will carry with it enough energy to lift the liquid higher than the apparatus. The apparatus working in this form may work somewhat like a combination of the system employing the open cock at the outlet and the system opening and closing the valve. retaining thus the advantages of both systems.

The conditions involved in the use and application of filters indicate the important effect which may be produced by small defects in the apparatus such as leakage, holes or couplings or connections which allow liquid to pass out. these defects being analogous to the bad effect produced in electrical circuits by bad contacts or by other defects in different parts of the apparatus, etc. The piston may work either with the cylinder horizontal or vertical or inclined, or any other suitable means may be employed to produce variations in compression in the liquid to set up the compression waves. The pipe through which liquid flows may be either horizontal or vertical or inclined. and it may be curved. bent or straight. All of these arrangements may be referred to as pumps. and the term pumping is used as including moving. transporting or conveying in vertical or horizontal or inclined directions or a combination of any of them. and the liquids so pumped may be simple liquids or may carry more or less solid matter or gases.

I claim as my invention:

1. The method of varying and adjusting the efficiency of pumping apparatus comprising a pipe carrying liquid an inlet and an outlet therefor and means for causing compression waves to pass through the liquid and thereby cause movement of liquid through the apparatus. comprising associating and communicating a wave filter with the pipe so as to modify the waves in the liquid.

2. Pumping apparatus comprising a pipe carrying liquid. an inlet and an outlet therefor. means for causing compression waves to pass through the liquid and thereby cause movement of liquid through the apparatus. a wave filter associated and communicating with the pipe so as to modify the waves in the liquid.

3. Pumping apparatus comprising a pipe carrying liquid. an inlet and an outlet therefor. means for causing compression waves to pass through the liquid and thereby cause movement of liquid through the apparatus. inertia. capacity and leakage associated and communicating with the pipe so as to modify the waves in the liquid.

4. Pumping apparatus comprising a pipe carrying liquid. an inlet and an outlet therefor. means for causing compression waves to pass through the liquid and thereby cause movement of liquid through the apparatus. inertia associated and communicating with the pipe so as to modify the waves in the liquid.

5. Pumping apparatus comprising a pipe carrying liquid, an inlet and an outlet therefor, means for causing compression waves to pass through the liquid and thereby cause movement of liquid through the apparatus. capacity associated and communicating with the pipe so as to modify the waves in the liquid.

6. Pumping apparatus comprising a pipe carrying liquid. an inlet and an outlet therefor, means for causing compression waves to pass through the liquid and thereby cause movement of liquid through the apparatus, inertia and capacity associated and communicating with the pipe so as to modify the waves in the liquid.

7. Pumping apparatus comprising a pipe carrying liquid. means for causing compression waves to pass through the liquid, whereby the waves cause liquid to flow through the apparatus, and an auxiliary wave filter associated and communicating with the pipe so as to modify the waves.

8. Apparatus for pumping liquids comprising a check valve in the liquid supply, a compressor at the point of delivery including a cylinder and a piston and an outlet pipe. a pipe filled with liquid extending from the valve to the compressor. means for reciprocating the piston rapidly through a short stroke whereby the compression of the liquid produced by the piston is varied and a wave filter associated and communicating with the last named pipe which when altered varies the output of the pump.

9. An apparatus for pumping liquid comprising a pipe filled with liquid leading to the liquid supply. a check valve in the pipe in the liquid supply. a compressor cylinder at the other end of the pipe, an open outlet from the cylinder. a piston to alternately compress the liquid in the pipe and release the pressure. and a wave filter associated and communicating with the pipe.

10. Apparatus for pumping liquid comprising means for alternately compressing a body of liquid in a pipe and releasing the pressure to set up waves in the liquid. an outlet for the pipe whereby the waves cause liquid to enter and flow through the pipe and auxiliary wave filters associated and communicating with the pipe which when altered vary the liquid flow through the pipe.

11. Apparatus for pumping liquid comprising means for alternately compressing a body of liquid in a pipe. separate means for alternately releasing the pressure. an outlet for the pipe whereby the variations in compression cause the liquid to enter and flow through the pipe and an auxiliary wave filter for varying the flow.

12. Apparatus for pumping liquids comprising a pipe leading to the liquid supply filled with liquid. a check valve in the pipe within the liquid to be moved. an outlet for the liquid. means for compressing the liquid in the pipe. separate means for suddenly releasing the pressure. and an auxiliary wave filter for varying the flow of the liquid.

13. Apparatus for pumping liquids comprising a pipe leading to the liquid supply and filled with liquid. a check valve in the pipe within the liquid supply. an outlet for the liquid. means to set up a contemporaneous plurality of series of compression waves in the liquid in the pipe to operate the check valve and move the liquid. and an auxiliary wave filter for varying the flow of the liquid.

14. Apparatus for pumping liquids comprising means for alternately compressing a body of liquid in a pipe and releasing the pressure. an outlet for the pipe, whereby the variations in

6   **1,941,593**

compression cause liquid to enter and flow through the pipe, and an enlargement connected with the pipe modifying the pumping effect.

15. Apparatus for pumping liquids comprising means for alternately compressing a body of liquid in a pipe and releasing the pressure, an outlet for the pipe, whereby the variations in compression cause liquid to enter and flow through the pipe, and an enlargement in the pipe modifying the pumping effect.

16. Apparatus for pumping liquids comprising means for alternately compressing a body of liquid in a pipe and releasing the pressure, an outlet for the pipe, whereby the variations in compression cause liquid to enter and flow through the pipe, and an obstruction in the pipe modifying the pumping effect.

17. Apparatus for pumping liquids comprising means for alternately compressing a body of liquid in a pipe and releasing the pressure, an outlet for the pipe, whereby the variations in compression cause liquid to enter and flow through the pipe, and an obstruction and an enlargement in the pipe modifying the pumping effect.

18. Apparatus for pumping liquids comprising means for alternately compressing a body of liquid in a pipe and releasing the pressure, an outlet for the pipe, whereby the variations in compression cause liquid to enter and flow through the pipe and an obstruction and an enlargement in a passageway connected with the pipe modifying the pumping effect.

19. The method of regulating the output of a pumping apparatus comprising means for alternately compressing a body of liquid in pipe, separate means for alternately releasing the pressure and an outlet for the pipe, whereby the variations in compression cause the liquid to enter and flow through the pipe, consisting of inserting and regulating, varying and/or adjusting auxiliary and additional wave filter elements.

20. The method of regulating the output of apparatus for pumping liquid comprising means for alternately compressing a body of liquid in a pipe, separate means for alternately releasing the pressure, an outlet for the pipe whereby the variations in compression cause the liquid to enter and flow through the pipe, and an auxiliary wave filter for varying the flow, consisting of regulating, varying and/or adjusting the auxiliary wave filter.

21. The method of regulating the output of apparatus for pumping liquids comprising a pipe leading to the liquid supply and filled with liquid, a check valve in the pipe within the liquid supply, an outlet for the liquid, means to set up a contemporaneous plurality of series of compression waves in the liquid in the pipe to operate the check valve and move the liquid, and an auxiliary wave filter for varying the flow of the liquid, consisting of regulating, varying and/or adjusting the auxiliary wave filter.

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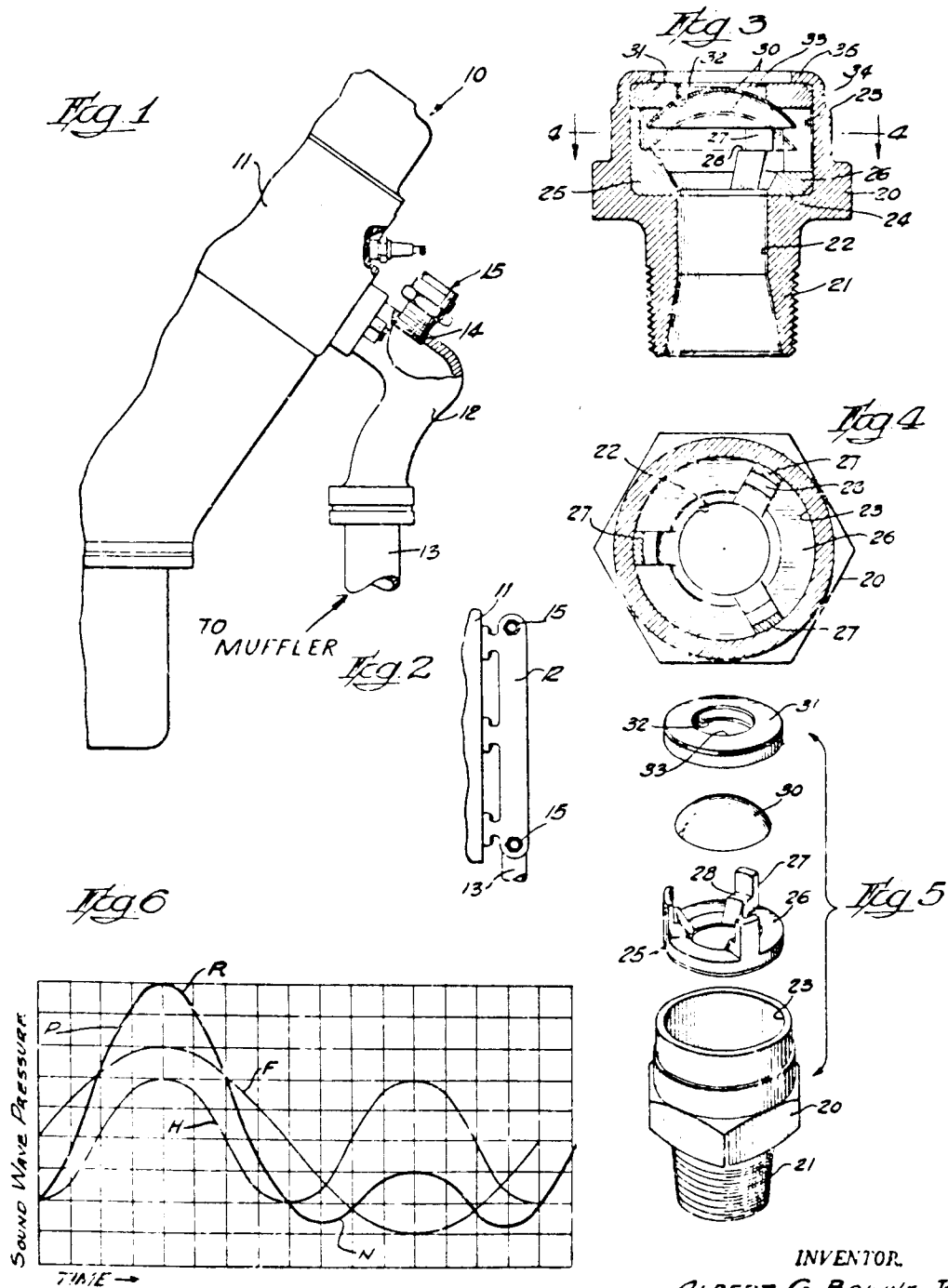
Oct. 7, 1958   A. G. BODINE, JR   2,854,316

SONIC ENGINE EXHAUST COMBUSTOR

Filed Aug. 2, 1956

Fig 1

Fig 3

Fig 4

Fig 2

Fig 5

Fig 6

70 MUFFLER

SOUND WAVE PRESSURE

TIME →

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ATTORNEY.

United States Patent Office

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This invention relates generally to systems for completing the combustion of exhaust gases from automotive engines.

It has now been determined that a large and important fraction of "smog" consists of incompletely burned hydrocarbon fuel exhausted by automotive engines. Numerous proposals have been made for completion of the combustion of such fuels, including the broad concept of admitting air to the exhaust manifold through a negative pressure responsive check valve in order to complete the combustion, but nothing of sufficient merit or practicability has so far emerged. Those prior systems which admit air through a negative pressure responsive check valve use valves which open in response to that negative pressure which follows the surge of gases through the exhaust system upon each opening of an exhaust valve. Such valves do not operate in response to or in phase with the sonic wave pattern in the exhaust system and do not create the sonic wave pattern characteristic of the present invention, as presently to be described.

A primary object of the present invention is the provision of a novel and improved system for periodically admitting air for completion of combustion to the exhaust manifold system via a special check valve made responsive to sonic wave phenomena in the exhaust system, and the operation of which valve modifies the normal sonic wave pattern in the exhaust system in such a way as to markedly improve completion of combustion.

According to the invention, the manifold is equipped with one or more negative pressure responsive air intake check valves, which are made to be frequency responsive to open and close in response to negative pressure half cycles of the sound wave pattern developed in the exhaust system. Considering first the idealized frequency sinusoidal sound wave developed in the exhaust system by the engine exhaust, a negative pressure responsive air intake check valve, assumed to be responsive to the frequency of the wave, would admit air to the system during each negative pressure half cycle, with the effect that the negative pressure half cycle is flattened. The effect is to introduce into the wave a strong second harmonic content. The positive half cycle of the resulting wave pattern is highly peaked. In order to assure effective valve action in consonance with the resultant complex sound wave pattern in the exhaust system, I make the intake check valve frequency responsive to the resultant sound wave pattern, i. e., that resulting from the normal exhaust system sound wave, modified by the second harmonic owing to air admitted by the check valve. It has been stated that the positive half cycle of the resultant wave is peaked owing to the operation of the sonically responsive check valve. I have found that a positively peaked sound wave is highly conducive to fuel combustion, and accordingly, I have created conditions under which unburned fuel in the exhaust gases may be most effectively consumed. In operation, the check valve thus opens on each negative half cycle of the sound wave,

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and closes during the positive half cycle. The small quantity of intaken air admixes with the exhaust gases in the manifold, and consumes a substantial quantity of unburned hydrocarbons during the immediate following peaked positive half cycle of the wave. Owing to the vigorous burning induced by the peaked sound wave, there is little or no carry over of air from one positive half cycle to the next, each charge intaken during a negative half cycle of the wave reacting substantially completely during the immediately following positive half cycle. Under these conditions, there is no material cooling of the exhaust gases by the introduced air. The making of the check valve frequency responsive to the wave pattern will be explained hereinafter.

The invention will be more fully understood from the following detailed description of a present illustrative embodiment of the invention, in which:

Fig. 1 is a fragmentary view of an automotive engine equipped with an exhaust manifold and intake check valve in accordance with the invention;

Fig. 2 is a plan view of the exhaust manifold of Fig. 1;

Fig. 3 is a vertical medial section through a form of air intake valve in accordance with the invention;

Fig. 4 is a section taken on line 4—4 of Fig. 3;

Fig. 5 is an exploded view of the components of the check valve of the invention; and

Fig. 6 is a diagram showing sonic wave patterns induced in the exhaust system by the invention.

In the drawings, numeral 10 designates a portion of a V-type internal combustion engine, a cylinder head thereof being indicated at 11, and the usual exhaust manifold at 12. Coupled to and extending from the bottom of the exhaust manifold is fragmentarily illustrated conventional exhaust pipe 13. Mounted in suitable threaded ports 14 in the wall of manifold 12 are one or more air intake check valves 15. As here illustratively shown, there is one such intake valve 15 at each end of the top wall 12a of the manifold.

The construction of a preferred illustrative check valve 15 is shown in Figs. 3-5. A valve body 20 has a threaded tubular stem 21 for installation in port 14, and the bore 22 through this stem meets enlarged cylindrical valve chamber 23 at shoulder 24. Seated in the bottom of chamber 23, on shoulder 24, is a valve stop member 25 comprising annulus 26 fitted closely inside chamber 23 and seating on shoulder 24. A plurality of valve guide elements 27 project upwardly from annulus 26, and have intermediate steps 28 forming limit stops for the valve element. The valve element comprises a thin domed shell 30 receivable with good clearance between the upper portions of the guide members 27, and adapted to engage, in the open position thereof, against steps or stops 28. Contained within chamber 23, guides 27, and resting on the upper ends of the latter, is valve seat ring 31, having seat 32 for the valve element, and port 33. The cylindrical outer wall portion 34 of the valve body is turned over seat ring 31, as indicated at 35.

Owing to exhaust pressure in the manifold, the valve element 30 stands normally in its upper, closed position, seated on ring 31. The valve element 30 is relatively light in weight, being composed of thin steel (such as stainless steel) and, generally stated, is movable in response to the sound wave pattern in the exhaust system. It is important that this valve member be light, and move in phase with the sound pressure wave in the exhaust system.

Operation of the system is as follows: The engine exhaust into and through the manifold and exhaust pipe by shock excitation, generates a sonic wave therein whose fundamental frequency is governed by manifold and ex-

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haust pipe dimensions and exhaust gas temperature. The fundamental frequency sonic pressure wave thus generated is represented at F in Fig. 6. The valve element 30 of each of check valves 15 is held closed by positive exhaust gas pressure. Negative wave pressure in the manifold will cause the valve 30 to unseat and admit air. Such admission of air, as previously described, flattens the negative half cycle of the fundamental frequency wave, which distortion generates a second harmonic wave component as represented at H in Fig. 6. The fundamental F and second harmonic H combine to produce the resultant wave pattern R, characterized by a peaked positive half cycle P, and a flattened negative half cycle N.

Air taken in through the valve during the negative pressure half cycle N reacts vigorously with unconsumed hydrocarbons during the peaked positive half cycle P. As before stated, such a peaked sound wave has been discovered to greatly promote fuel combustion. The theory of fuel combustion in presence of sound waves is an involved subject, and only partially understood by authorities. No attempt need be made to set forth such theory herein, but it is a demonstrated fact that fuel combustion is accelerated and particularly excited by peaked positive waves resulting from harmonic content. The air taken in during the negative half cycle is thereby substantially completely consumed on the next succeeding positive half cycle in reacting with previously unburned hydrocarbons. The amount of this intaken air on each negative half cycle may be small, so that no material cooling effect takes place such as would retard the combustion. It is an important concept of the invention that, on each negative half cycle of the sonic wave, a small amount of air is taken in through the check valve, and substantially completely used in an accelerated combustion reaction during, and by virtue of, the next succeeding peaked positive half cycle.

As mentioned earlier herein, one concept of the invention is the provision of an air intake check valve that is frequency responsive to the complex wave pattern resulting from the combination of the fundamental with its harmonic content, so that the valve will unfailingly open during the negative half cycle of the wave pattern, and close during the positive half cycle thereof. It must move in step with the sound pressure wave without material phase lag. The illustrative valve described hereinabove is made responsive to this sound wave pattern by adjustment of the acoustic mass reactance of its movable valve element relative to the product of the area of its orifice and the pressure differential across it. Thus, f, the optimum response frequency, is given by the ratio of the average cyclic pressure to the acoustic mass reactance of the valve element. In symbolic terms,

$$f = \frac{A \Delta p}{X_1}$$

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where X_1 is equivalent acoustic mass reactance, A is the effective area of the valve orifice, and Δp is the pressure differential across the orifice. Following this theory, those skilled in the acoustics art will readily understand the proportioning of the valve for frequency response to the wave pattern developed in a given engine exhaust system.

One illustrative embodiment of the invention has now been described, but it will be understood that various modifications are possible within the scope of the invention. For example, while I have here shown the air intake check valves mounted in the manifold, they may be located at any place in the exhaust system where the sound wave is strong. The location should not, of course, be in the region of the muffler, where the sound wave is attenuated, and ineffective to operate the valve properly. But the valve can be located in the exhaust pipe downstream from the manifold, so long as it opens into the exhaust system at a point where the sound wave is strong enough to operate it. Various modified forms of intake valve conforming to the sonic response requirements heretofore given are also possible within the scope of the invention.

I claim:

In combination with an automotive engine exhaust system comprising an exhaust manifold, and an exhaust pipe and muffler wherein a sonic pressure wave is generated by engine exhaust, means for completing combustion of unburned fuel in the exhaust system comprising an air intake check valve opening into said exhaust system at a point therein substantially spaced upstream from said muffler where said sonic pressure wave is substantially unattenuated, said check valve having a movable valve element for opening and closing said valve in step and in phase with negative and positive half-cycles, respectively, of said sonic pressure wave, so as to cause intake of air during said negative half-cycles and resulting reduction in the amplitude of said negative half-cycles, thereby superimposing on said sonic pressure wave a second harmonic, yielding a complex resultant wave characterized by peaked positive pressure half-cycles and flattened negative pressure half-cycles, said movable valve element being frequency responsive to said complex resultant wave to open and close during and by virtue of said flattened negative pressure half-cycle and to remain closed during said peaked positive pressure half-cycle, whereby air charges admitted during the negative pressure half-cycles of the sonic wave react with unburned fuel in the exhaust system during and by virtue of the peaked positive pressure half-cycles of the sonic wave.

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United States Patent

Hudspeth et al.

[15] **3,666,038**

[45] **May 30, 1972**

[54] **AIR PULSING SYSTEM**

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[73] Assignee: **FMA, Inc., Eugene, Oreg.**

[22] Filed: **Oct. 8, 1970**

[21] Appl. No.: **79,124**

[52] **U.S. Cl.** ....180/66 B, 60/57 R, 60/62, 417/231

[51] **Int. Cl.** B60k 3/00, B60k 27/00

[58] **Field of Search** ....180/66 B, 66 R; 60/62, 57 R, 60/57 T, 6; 417/231, 233

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Primary Examiner—Benjamin Hersh
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Attorney—James D. Givnan, Jr.

[57] **ABSTRACT**

A system utilizing a pressure storage vessel for initially charging a first air cylinder of a series of air cylinders. Valve means admits a flow of pressurized air, in a sequential manner, into the cylinders for piston movement downwardly to compress spring members to a loaded condition. Additional valve means, closed during downward piston movement, are subsequently actuated to permit discharge of an air impulse, by the action of said spring combined with a second source of air pressure acting on the underside of the piston. The last cylinder of the series is operable to impart a force to a media for the operation of a motor for powering a vehicle.

7 Claims, 3 Drawing Figures
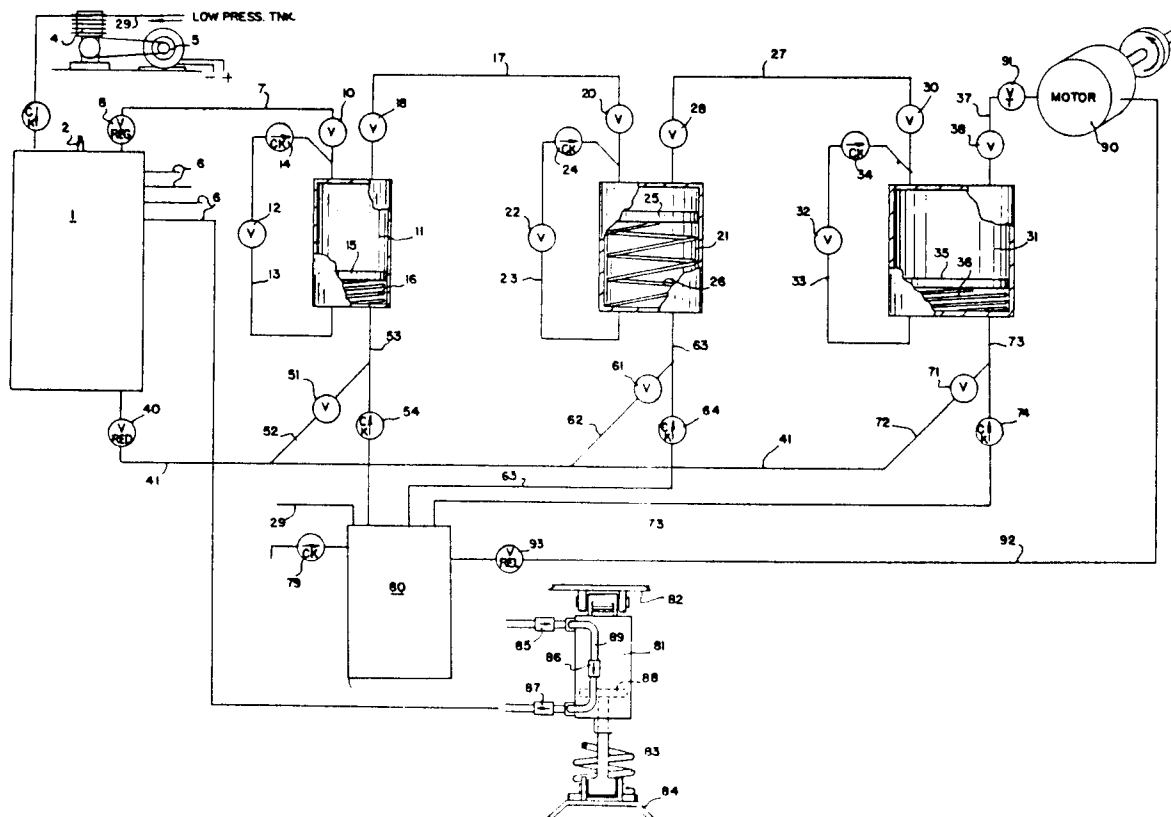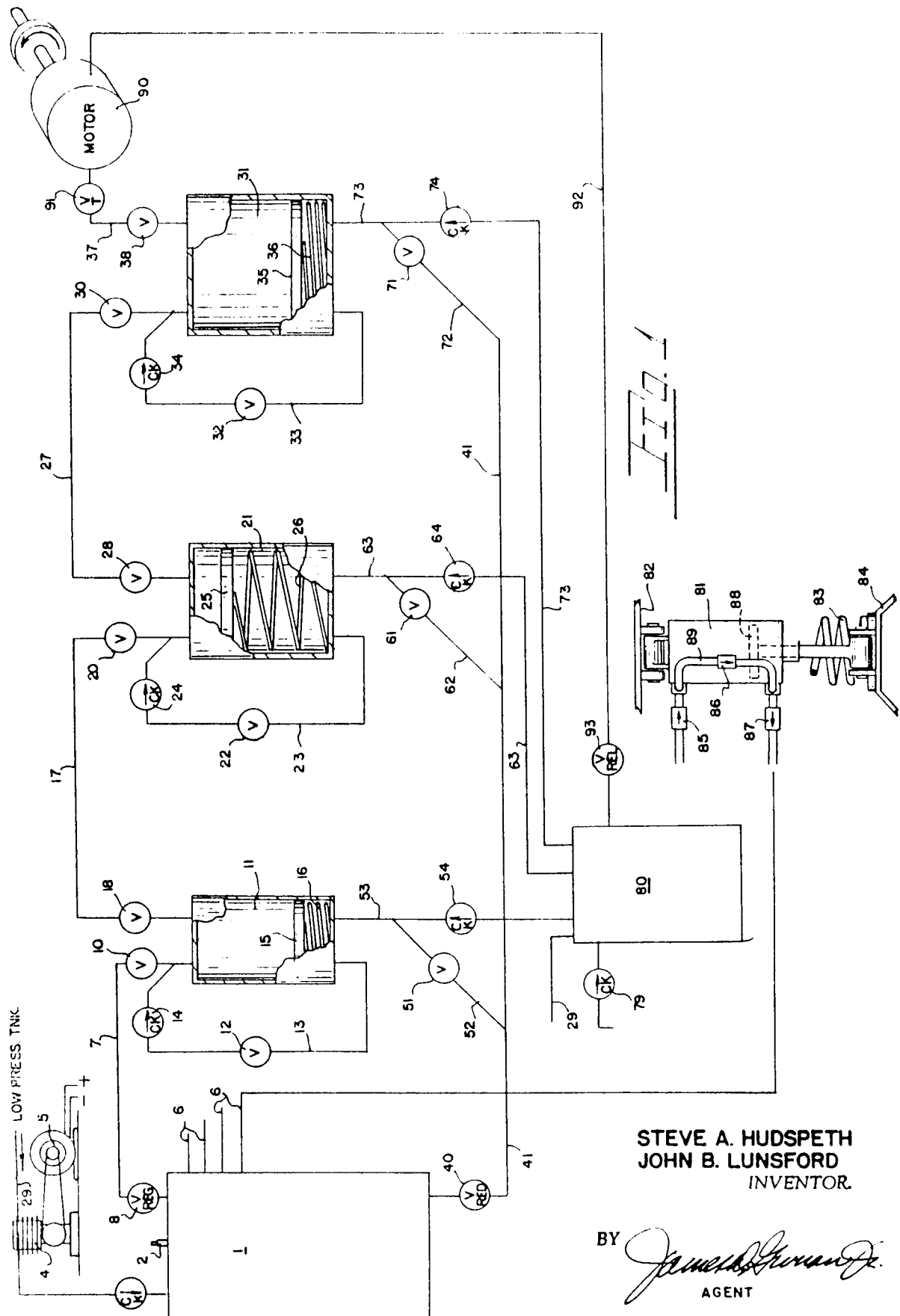
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Fig 2

Fig 3

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AIR PULSING SYSTEM

BACKGROUND OF THE INVENTION

The present invention relates generally to a system for converting a pressurized air flow into a pulsating air flow wherein the air impulses are utilized to impart movement to a motor for powering of a vehicle.

The use of air as a media for imparting a driving force to the power train of a vehicle has, to a large extent, not proved practical. Further, the use of fluid powered motors associated in direct drive with a vehicles wheels also has apparently not proved practical for one reason or another. In such embodiments, fluid as a media for transmitting power is pressurized to provide a constant pressure flow through fluid motors associated with the vehicle wheels. The pumps in such arrangements are powered by the vehicles internal combustion engines.

SUMMARY OF THE INVENTION

The present invention is embodied in a series of cylinders with each cylinder having both a piston reciprocal therein responsive to differential pressures and resilient means acting on its piston. Air flows sequentially through t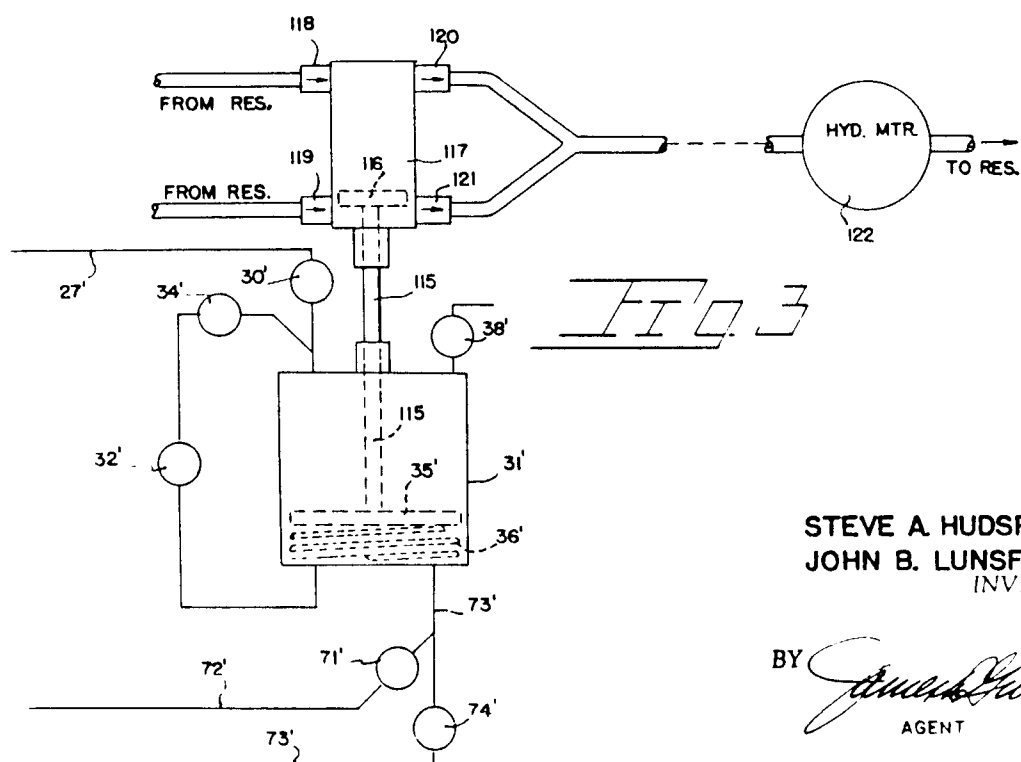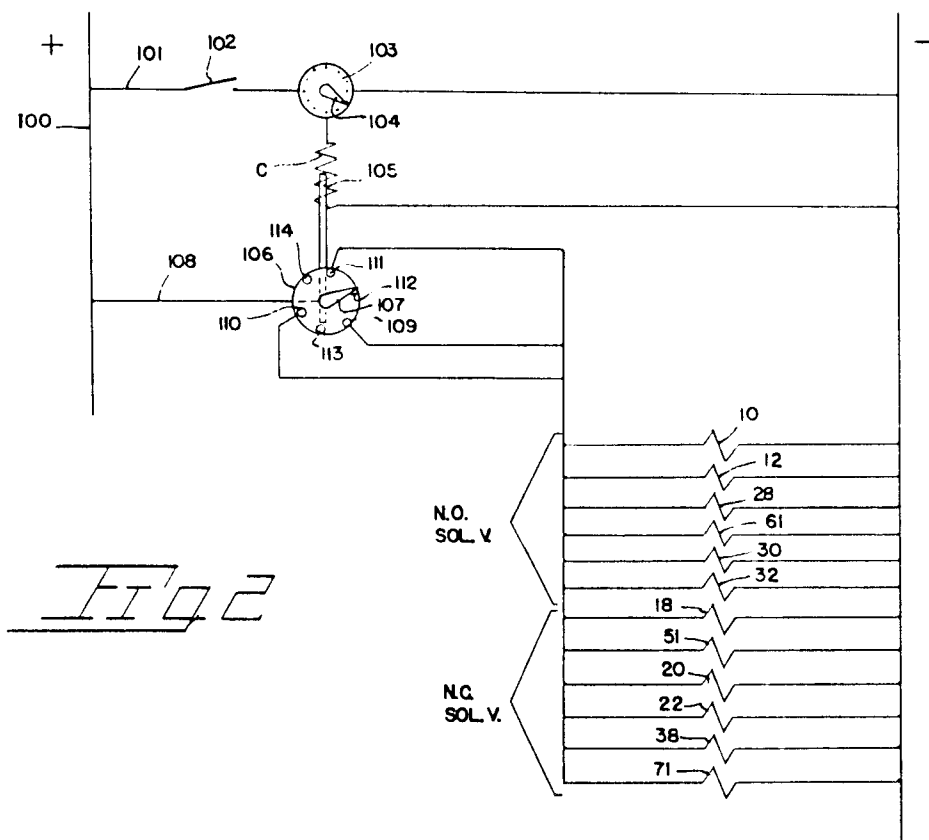he cylinders and ultimately past an air motor for conversion of the air flow to mechanical power. Air conduits in communication with each cylinder direct an air flow alternately to opposite sides of their piston therein with the air being forcefully discharged from each cylinder by the combined action of air pressure and the resilient member associated with the cylinder. Downstream of the motor is a low pressure tank constituting a source of low pressure air. Low pressure air is utilized to assist the resilient member of each cylinder to forcefully exhaust the air from the cylinder.

A high pressure tank provides an initial flow of high pressure air to the first cylinder of the series of cylinders. The tank may be of the type intermittently charged by compressor means or a storage tank capable of receiving periodic charges of air or a combination thereof.

BRIEF DESCRIPTION OF THE DRAWING

In the accompanying drawing:

FIG. 1 is a schematic of the air pulsing system,

FIG. 2 is a wiring schematic, and

FIG. 3 is a schematic of a portion of the pulsing system showing a modification thereof.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

With continuing reference to the drawings in which applied reference numerals indicate parts similarly identified in the following specification, the reference numeral 1 indicates a pressure storage vessel, charged with air in the present embodiment and for present purposes is termed a high pressure tank and may include conventional accumulator means.

For charging of the tank from an external air source, the tank is fitted with a valve at 2. While the term air is used it will be understood that other medias such as hydraulic fluid may be used within the scope of the invention. An additional source of pressurized air for tank 1 is in the form of a compressor at 4 powered by an electric motor 5. Constituting another or alternative source of air under pressure are tank supply lines at 6 each in communication at their unseen ends with air cylinders. The air cylinders are disposed adjacent each wheel of the vehicle for powering by travel of the wheel suspension member in relation to the vehicle frame and are, in combination with additional elements, the subject of a co-pending patent application, serial No. 97,125 filed Oct. 8, 1970, and entitled Vehicular Air Compression System. The tank 1 of the present system may be pressurized by one or more of the means above described. Details of the air cylinder are later described.

Exiting from tank 1 is a high pressure conduit 7 with a pressure regulator 8 therein. In one embodiment of the invention a

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line pressure of 80 PSI is provided to a first solenoid operated inlet valve 10 controlling the entry of air into a first air cylinder 11 of a series of air cylinders including cylinders at 21 and 31 each of increasing volume. Corresponding to valve 10 for controlling air to those other air cylinders are solenoid operated inlet valves 20 and 30 while similar valves at 12, 22 and 32 hereinafter referred to as transfer valves control the air flow intermediate the ends of each cylinder. These latter valves are located in transfer lines 13, 23, 33 communicating the opposite ends of each cylinder with check valves at 14, 24 and 34 for unidirectional air flow as indicated. Valves 10, 12 and 30, 32 are normally (deenergized) open in the present embodiment while valves 20, 22 are normally closed.

Each cylinder includes a piston 15, 25 and 35 biased by an internal compression loaded helical spring at 16, 26 and 36 toward the high pressure inlet side of the cylinders. The springs 16, 26 and 36 each have progressively greater spring rates for exerting a greater force on their respective pistons.

Exhaust conduits at 17, 27 and 37 for the series of cylinders directs air past exhaust control valves respectively at 18, 28 and 38 with exhaust conduits 17 and 27 being in communication with the solenoid operated inlet valves 20 and 30 serving the second and third air cylinders. Valves 18 and 38 are normally closed with valve 28 being of the normally open type.

What may be termed a low pressure air system provides that area below each of the pistons of each cylinder with a source of air under 10 PSI (above atmospheric) for actuation of their piston in the direction of spring biased movement. A low pressure regulator 40, in a conduit 41, reduces downstream pressure in conduit 41 to approximately the 10 PSI. Indicated at 51, 61 and 71 are solenoid operated valves in lines 52, 62 and 72 all branching off from conduit 41. Valves 51 and 71 are of the normally closed type while valve 61 is normally open.

Additionally included in the low pressure system is a low pressure storage tank 80 constituting a second source of low pressure air for the cylinders 11, 21 and 31. A check valve at 79 admits air to tank 80 when less than atmospheric pressure is in the tank. Air exits tank 80 via lines 53, 63 and 73 past check valves 54, 64 and 74 with said lines incorporating Y connections to receive lines 52, 62 and 72. The check valves 54, 64 and 74 are of the conventional spring biased type with the closing action of their springs offset in a combined manner by the negative upstream pressure during a merging air flow from line 52 into line 53. An air line 29 is advantageously used to provide a source of low pressure air from tank 80 to compressor 4.

Served by exhaust conduit 37 is an air motor 90 to which a pulsating flow of air is provided past a regulating valve 91. The motor 90 may be of a conventional type such as a sliding vane type. A flywheel at 92 may be utilized to modify the effect of the irregular air impulses on the rotational speed of the motor shaft.

It will be apparent that the motor 90 may be fed by a second series of like cylinders, if desired, to provide air impulses at a greater frequency to said motor.

With reference to the wiring schematic of FIG. 2 one side of an electrical source is indicated at 100, a first circuit includes lead 101 with an off-on master control switch 102 therein closeable to energize a timer 103 with a rotor arm 104 for closing a second circuit at desired intervals to a coil C actuating the armature 105 of a stepping switch 106. Stepping switch 106 and its switch arm at 107 are operated by armature 105 to close circuits in alternate positions for operation of the solenoid operated valves. Moveable switch arm 107 of the stepping switch, in circuit via a conductor 108 with the electrical source, moves into timed contact with the contacts at 109, 110 and 111 to actuate said valves with alternate arm positions at 112, 113, and 114 opening the valve operating circuits to permit said valves to return to their normal position.

With a pulsing cycle starting with the valves in their normal (deenergized) positions air flows past valve 10 into the top end of cylinder 11 with air below the piston being ported past open valve 12 and check 14 for convergence with the incoming air.

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Simultaneously for the second cylinder 21, normally closed valve 20 is closed as is valve 22 while normally open valves 28 permits a pulse of air to be exhausted from cylinder 21 by action of the spring biased piston 25 supplemented by spring 26 and an incoming air flow entering past open valve 61 and check 64.

Simultaneously for the third cylinder 31, normally open valve 30 admits the air impulse into the cylinders top end while air below the descending piston is transferred past normally open valve 32 and check 34 for mergence with the incoming flow of air. Normally closed valves 38 and 71 are closed at this time preparatory to the stepping switch energizing the solenoid valves at which time the condition of the valves is reversed to permit spring 36, assisted by an incoming air flow, to forcefully travel to the upper end of cylinder 31 discharging an impulse of air to motor 90.

For purposes of completeness of the present disclosure the wheel air cylinder is indicated at 81 and, as aforesaid, is included in the subject matter of a second U.S. patent application filed by the present inventors. The cylinder 81 is attached at its upper end to a vehicle frame member 82 and oppositely the cylinders piston rod end 83 is connected to a wheel suspension member 84 of a vehicle. Check valves at 85, 86 and 87 permit a flow of air as indicated into the upper end of cylinder 81 from whence it is expelled by the upward stroke of piston 88. A transfer conduit at 89 directs said flow to the rod side of the rising piston 88 during raising movement of the suspension member 84. Subsequent opposite movement of the suspension member 84 as urged by the vehicle suspension spring 92 causes piston 88 to exhaust air therebelow past check 87 to tank 1.

A modified form of the invention is disclosed in FIG. 3 wherein the third cylinder of the above described form of the invention is replaced by a cylinder 31'. Valves at 30', 32', 38', 71', and 74' in air lines 27', 72' and 73' all function in accordance with the first described form of the invention. A departure exists in that the piston 35' urged by spring 36' is provided with a piston rod 115. The rod 115 terminates upwardly in a second piston 116, the latter being the piston of a double acting hydraulic pump at 117. An incoming flow enters alternately through check valves 118–119 while fluid is alternately exhausted, under pressure, past check valves 120–121 to a hydraulic motor 122. It is to be understood that the hydraulic circuit would include the normal components of any hydraulic circuit, e.g., pressure relief and flow control valves, etc.,.

Motors 90, and 122 of the modified form, may drive through suitable transmission and drive train components well known to those skilled in the present art.

While we have shown but two embodiments of the invention it will be apparent to those skilled in the art that the invention may be embodied still otherwise without departing from the spirit and scope of the invention.

Having thus described the invention what we desire to secure under a Letters Patent is:

1. A system for converting air under constant pressure to a pulsating air flow wherein the air impulses at peak pressure are of a substantially greater pressure value than said constant pressure for driving of a motor, said system comprising,

a pressure storage vessel,

a series of air cylinders each of progressively greater volume adapted to receive an air charge in an alternating manner, piston means within each of said cylinders, compressible means associated with each of said pistons and actuated upon the downward stroke of its piston for the conservation of energy expended by the piston, an air transfer line extending intermediate the ends of each cylinder and a

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transfer valve in each of said lines,

a fluid operated motor driven by the last cylinder of the series,

high pressure conduits intercommunicating the upper ends of said cylinders to provide same with a source of pressurized air, the first cylinder of the series receiving air via a high pressure conduit from said storage vessel with the remaining cylinders of the series receiving air moving sequentially through said cylinders,

inlet valves in said conduits admitting air under pressure to the upper ends of the cylinders for downward displacement of their pistons,

exhaust valves also in said conduits permitting an exhaust of air from the upper ends of the cylinders during upward piston movement,

low pressure conduits in communication with the lower ends of said cylinders and in communication with a source of low pressure air,

valves in said low pressure conduits permitting a flow of low pressure air through said last mentioned conduits into the lower ends of the cylinders during upward travel of said pistons, and

a control circuit simultaneously opening the inlet valve and transfer valve associated with each cylinder for admitting a flow of high pressure air and air transferred from the bottom side of the cylinder, said control circuit simultaneously closing the exhaust valve and the low pressure valve associated with each cylinder during the downstroke of the piston, said circuit operable additionally to simultaneously reserve the positions of the valves whereby the piston under the influence of low pressure air and said compressible means causes an impulse of air to be exhausted into the high pressure conduit and to a subsequent cylinder of the series with the piston of the last cylinder of the series operable to impart a force to a media for the operation of a motor.

2. The system as claimed in claim 1 installed on a vehicle and additionally including wheel air cylinders disposed intermediate the frame and movable wheel suspension members of a vehicle, said air cylinders constituting an air pumping means for charging said pressure storage vessel.

3. The system as claimed in claim 1 wherein said transfer line of each piston and the high pressure conduit serving the piston merge whereby a combined flow of air and air exhausted from the lower end of the cylinder enter the upper end of the cylinder.

4. The system as claimed in claim 1 additionally including a low pressure tank to receive the air exhausted by said fluid operated motor, additional low pressure conduits communicating the low pressure tank with the lower end of said cylinders.

5. The system as claimed in claim 4 wherein each of said cylinders is supplied with a merging flow of low pressure air said additional low pressure conduits including check valves.

6. The system as claimed in claim 1 wherein said compressible means comprises a helical compression spring housed within each of said cylinders, said springs having a spring rate increasing proportionally to the diameter of the cylinders.

7. The system as claimed in claim 1 additionally including a low pressure tank in receiving communication with said fluid motor, said low pressure conduits including both conduits in communication with said last mentioned tank and the cylinders and additional conduits in communication with the pressure storage vessel via pressure reducing means whereby either said lower pressure tank or said vessel may supply low pressure air to the underside area of the pistons.

* * * * *

United States Patent [19]

Schaefer

[11] **3,791,349**

[45] **Feb. 12, 1974**

[54] **STEAM GENERATOR**

[75] Inventor: **Carl D. Schaefer,** Chicago, Ill.

[73] Assignee: **Sonaqua Inc.,** Chicago, Ill.

[22] Filed: **Jan. 29, 1973**

[21] Appl. No.: **327,430**

[52] **U.S. Cl.** 122/11, 122/26
[51] **Int. Cl.** F22b 3/06
[58] **Field of Search** 122/11; 126/26, 247

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Primary Examiner—Kenneth W. Sprague
Attorney, Agent, or Firm—Kenneth T. Snow

[57] **ABSTRACT**

An apparatus and method for the production of steam and pressure by the intentional creation of shock waves in a distended body of water. The created shock waves are in the nature of water hammer and it is this water hammer which is repeated and intensified to such an extent the heat and pressure developed in the water converts the water into usable steam.

15 Claims, 8 Drawing Figures
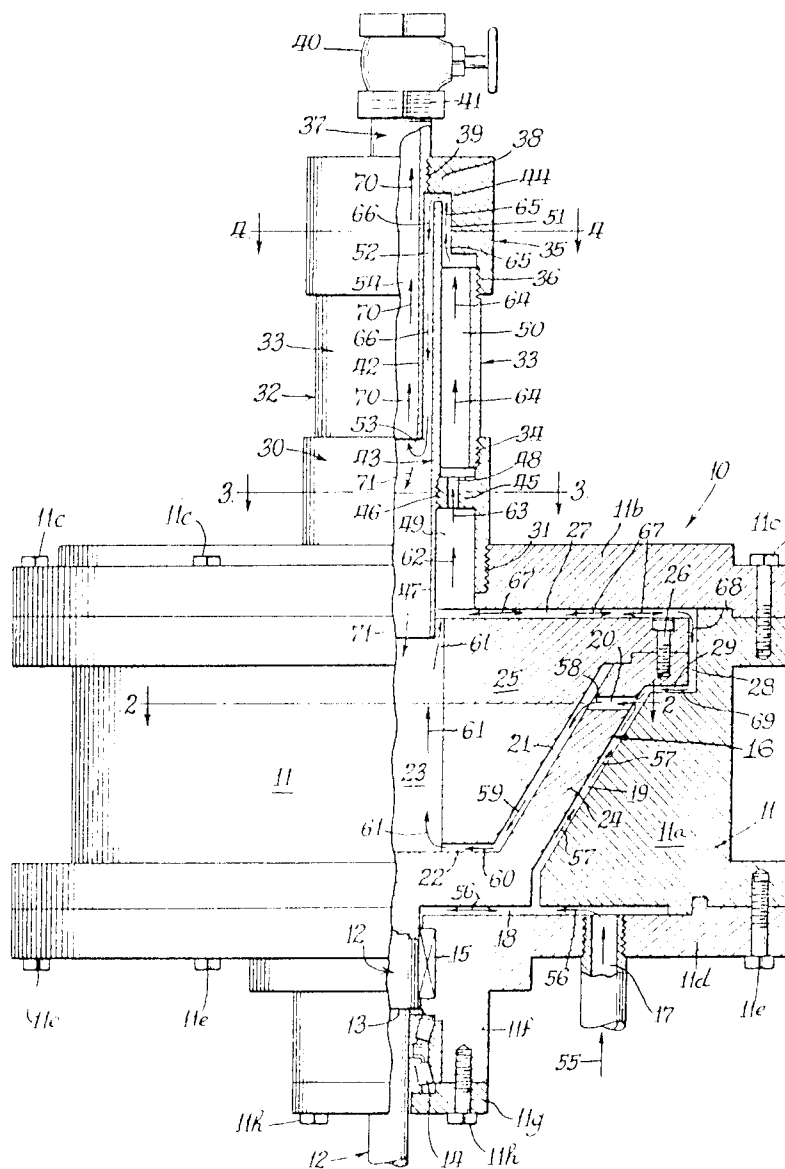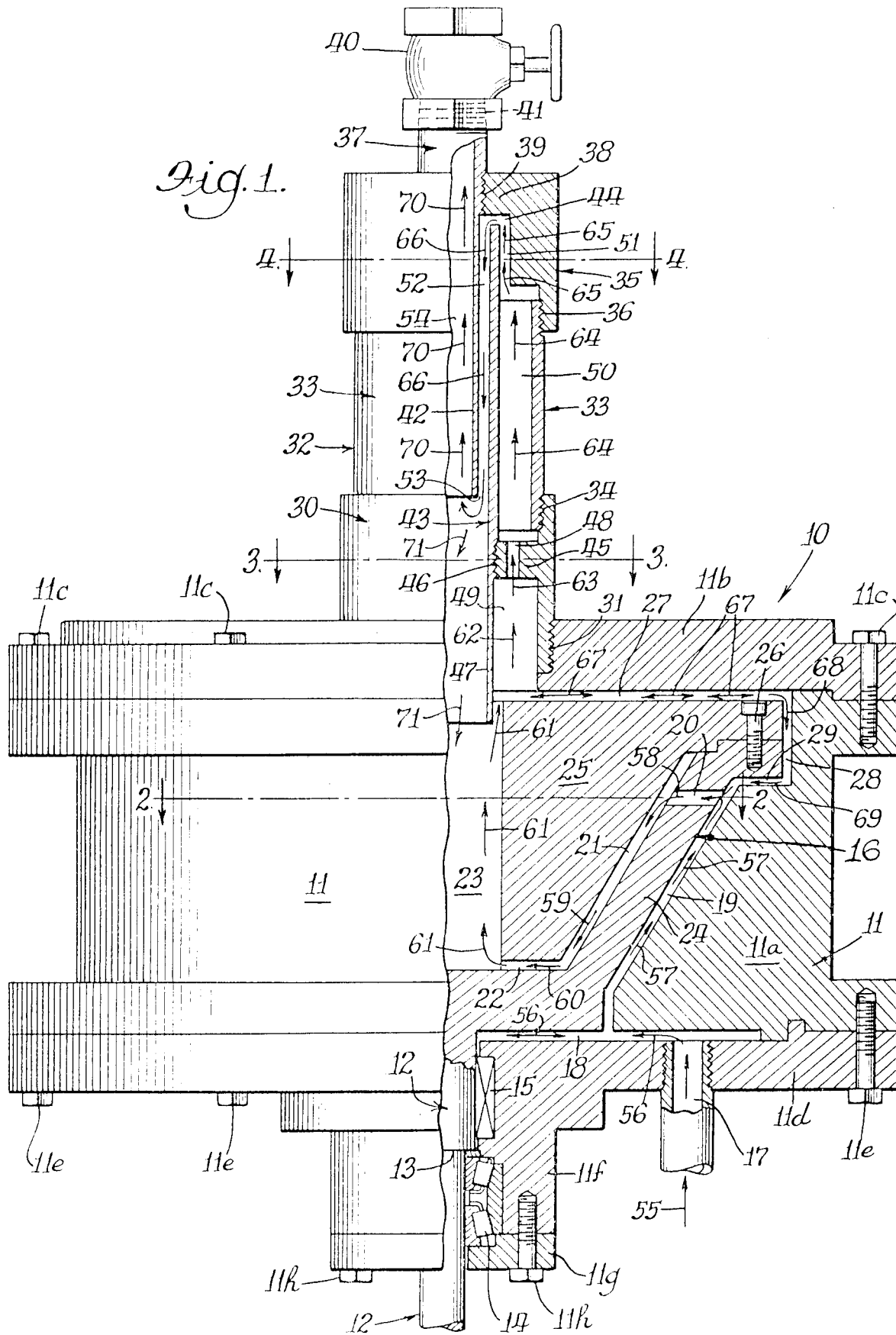
Fig. 1.

Fig.2.

Fig.3.

Fig.4.

Fig. 5.

Fig. 6.

Fig. 7.

Fig. 8.

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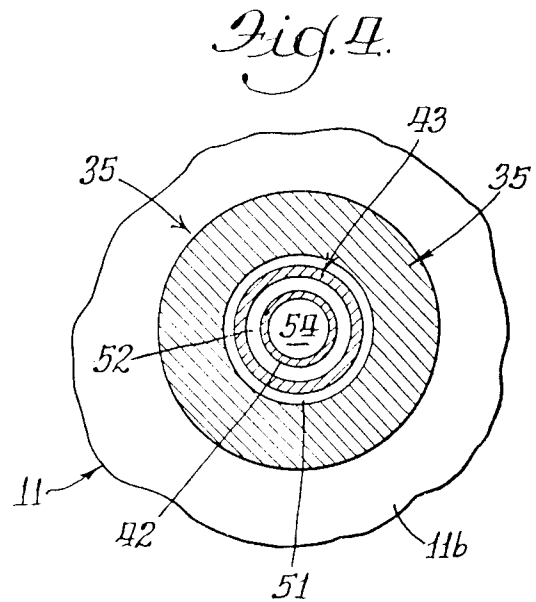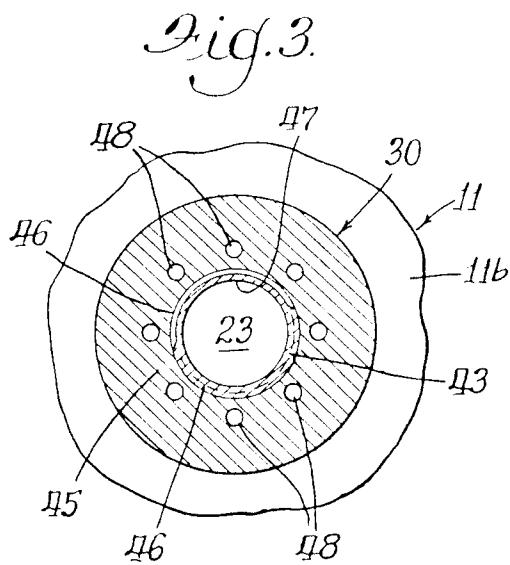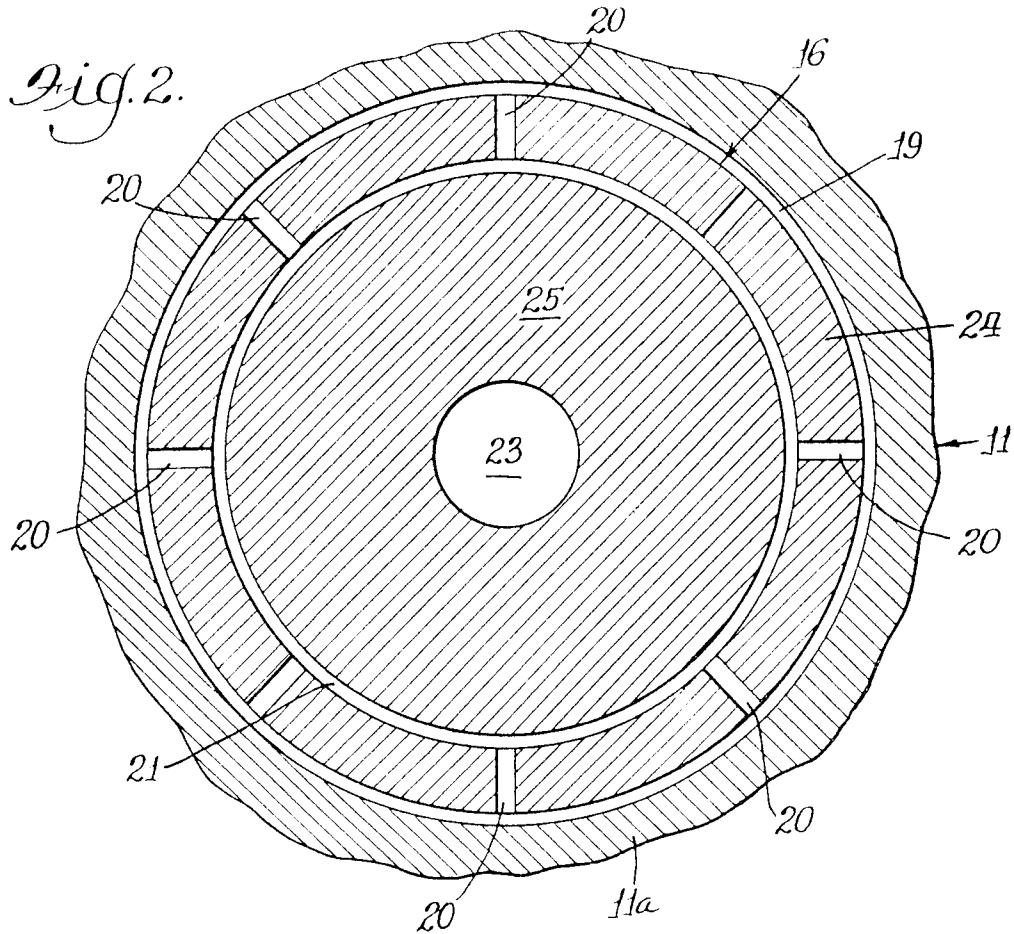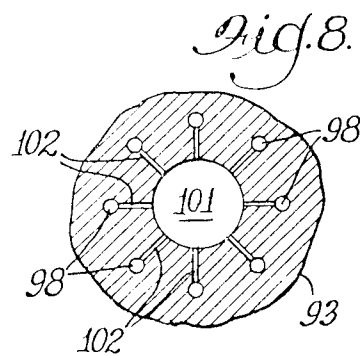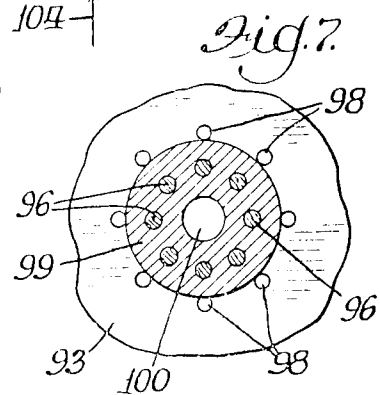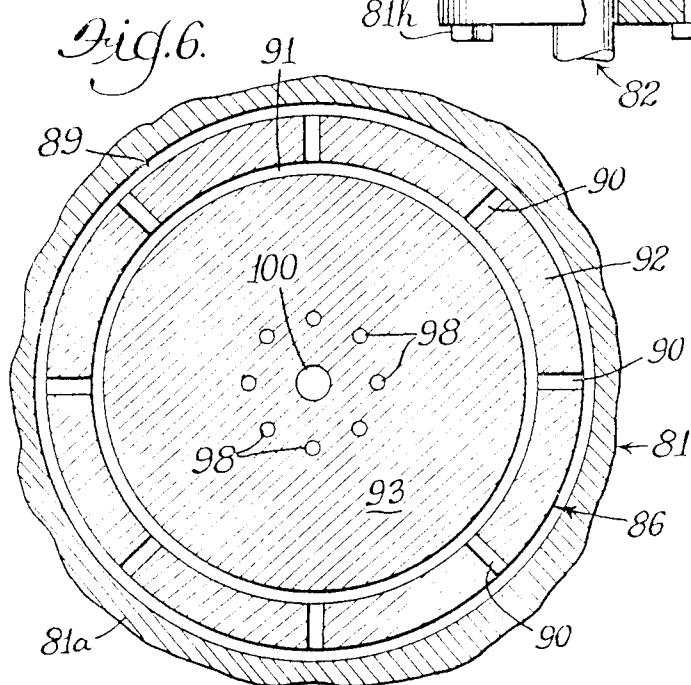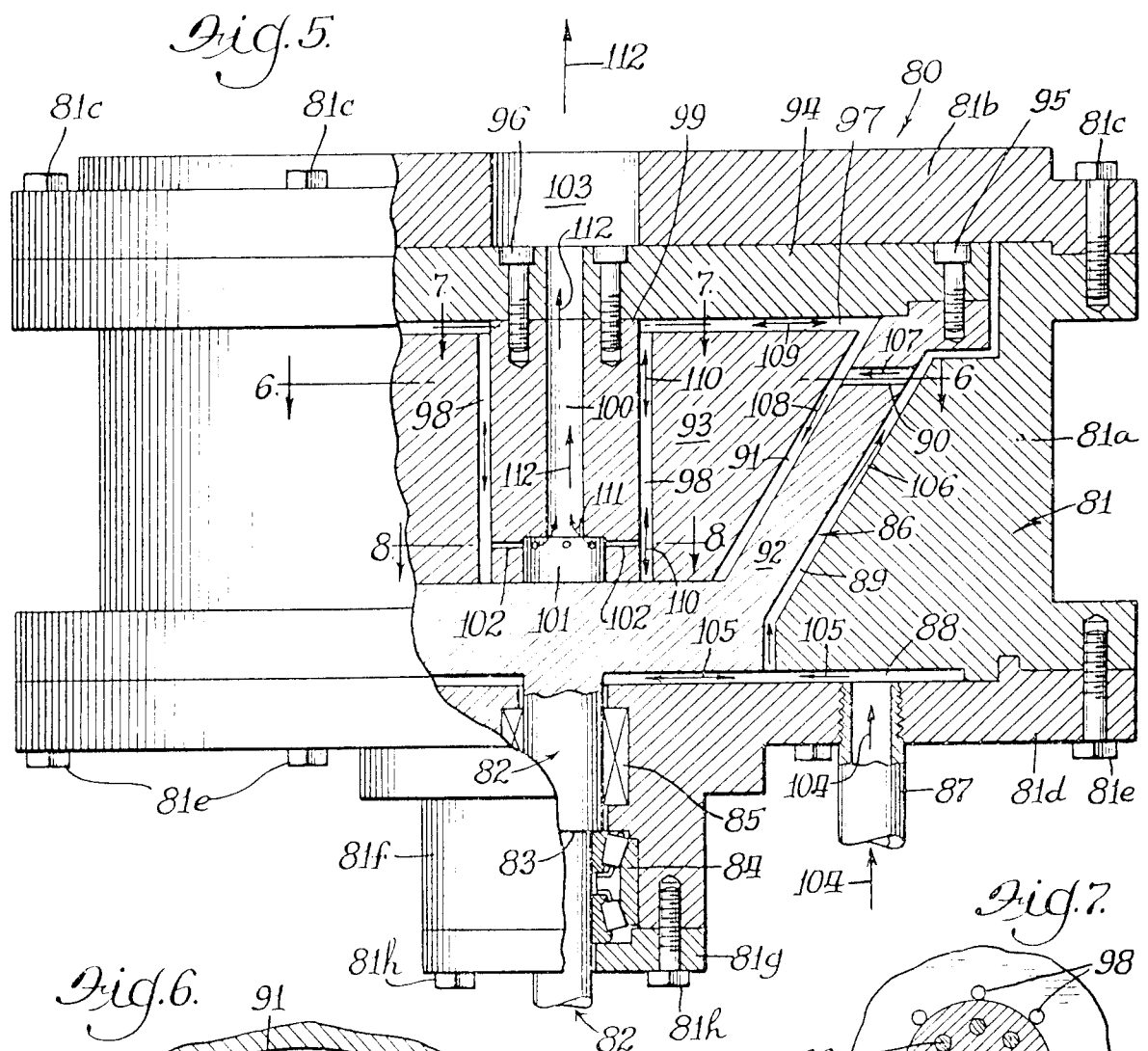
STEAM GENERATOR

BACKGROUND OF THE INVENTION

1. Field of the Invention

Steam generators have been in use for many years. Such generators have primarily employed burnable fuels to raise the temperature of a body of water until the water changes into steam. The uses of steam generators have been many. Many building heating systems employ steam as the heating medium. Many chemical processes employ steam to produce certain chemical reactions. Some of these use the steam as a source of heat or to contribute to the reaction while others use the steam as a catalyst to promote the desired reactions. Many physical problems are aided by the use of live steam. For example, certain types of mining operations employ steam to expedite the removal of minerals from the ground. Also, in the drilling for petroleum and gas it is often desired to use live steam to cause the start of the upward discharge of these liquids and gases once pockets of them have been reached by drilling.

It is concluded that steam generators in the past have been useful and will continue to be useful in the future — especially if a more economical steam generator is available. The steam generator of this present invention is such an economical device.

2. Description of the Prior Art

The use of water hammer for the generation of steam has just not been previously done to the best of our knowledge. However, physicists and engineers have long known of the existence of water hammer. Various books and texts have discussed water hammer and its attendant characteristics. Attention is directed to:

B. S. Massey: *MECHANICS OF FLUIDS*, Van Nos Rinhold, 1971, (pages 412 to 427).

John N. Bradley: *SHOCK WAVES IN CHEMISTRY AND PHYSICS*, London: Metchuen, New York: Wiley, American Press 1962, (pages 172 and 173).

Horace Williams King: *HANDBOOK OF HYDRAULICS, FOR THE SOLUTION OF HYDRAULIC PROBLEMS*, 4th Edition, Revised by Ernest F. Brater, New York, McGraw-Hill, 1954, (pages 6–21 to 6–27).

A patent search has been made on the device as disclosed herein and this search has confirmed out belief that no one heretofore has conceived of such a device.

U.S. Pat. No. 3,141,296 to Jacobs, Jr., et al. describes the utilization of shock waves produced in a liquid by an electric discharge to perform useful work. The shock waves are created by discharging electricity in a liquid filled chamber and the useful work is defined as a pump for the liquid.

U.S. Pat. No. 3,398,686 to Guin describes a motor which utilizes the power of shock waves created in a liquid by the discharge of electricity across a spark gap. Thus both Jacobs, Jr. and Guin are very similar to each other and it is obvious neither one produces shock waves in a body of liquid to produce an appreciable rise in temperature of that liquid. Also, neither one has created shock waves in a body of liquid by a mechanical means corresponding to water hammer to cause the temperature of that water to rise sufficiently to convert the water to steam.

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Other steam generators having water chambers appearing similar to applicant's water chambers are: Loeffler, U.S. Pat. No. 2,316,522; Gray, U.S. Pat. No. 3,508,402; Rennolds, U.S. Pat. No. 3,690,302. However, no one of these patented devices uses shock waves to cause the heating of the water — rather each one employs a combustible gas to effect a heating of the water for its conversion to steam. And, on close analysis each chamber is entirely different from applicant's chamber and lacking in the shock wave generating mechanisms as subsequently defined in this specification.

SUMMARY OF THE INVENTION

A principal object of the present invention is to provide a novel steam generator.

An important object of this invention is to provide a steam generator having a distended body of water which is subjected to shock waves.

Another important object of this invention is to provide a novel device to produce and intensify a series of water hammers within a distended body of water to thereupon substantially raise the temperature and pressure of such water.

Still another important object of this invention is to provide a novel means for creating a water hammer within a body of water.

An important object of this invention is to provide a device as set forth in the preceding object in which the water hammer is caused by alternating forces — first a centrifugal action and second a vacuum action — causing the body of water to be first pulled in one direction and then to snap back in an opposite direction.

Another and still further important object of this invention is to provide a device of the preceding two objects in which the distended body of water includes at least one closed bottom passageway in which the movement of water therein is suddenly extinguished and in which the snapping back and forth action of the water column occurs to thereby intentionally impart a water hammer to the body of water and substantially raise the temperature of the water so that a portion thereof is being continuously converted to live steam.

Other and further important objects and advantages will become apparent from the disclosures in the following specification and accompanying drawings.

IN THE DRAWINGS

FIG. 1 is an elevational view of a preferred embodiment of the steam generator of this invention with portions thereof in cross section.

FIG. 2 is a sectional view taken on the line 2—2 of FIG. 1.

FIG. 3 is a sectional view taken on the line 3—3 of FIG. 1.

FIG. 4 is a sectional view taken on the line 4—4 of FIG. 1.

FIG. 5 is an elevational view of a modified embodiment of the invention and with portions thereof in cross section.

FIG. 6 is a sectional view taken on the line 6—6 of FIG. 5.

FIG. 7 is a sectional view taken on the line 7—7 of FIG. 5.

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FIG. 8 is a sectional view taken on the line 8—8 of FIG. 5.

AS SHOWN IN THE DRAWINGS

The reference numeral 10 indicates generally the preferred embodiment of the steam generator of this invention. A stationary housing 11 encloses the steam generator 10. The housing comprises a main body portion 11a, an upper cap 11b fastened to the central body portion 11a by a circularly arranged series of cap screws 11c, an under cap 11d fastened to the body portion 11a by a circularly arranged series of cap screws 11e, a downwardly projecting central tubular portion 11f forming a part of the under cap 11d, and a bottom cover 11g fastened by a series of circularly arranged cap screws 11h to the central tubular portion 11f.

A vertically disposed motor driven shaft 12 having an annular shoulder 13 therearound is journally carried within the central tubular portion 11f of the housing 11 by means of a roller bearing 14. The inner race of the bearing 14 is disposed between the annular shoulder 13 of the rotating shaft 12 at its top and the stationary cover 11g at its bottom. An annular seal 15 is held within the housing 11 and brushes against the rotating shaft 12 to effect a sealing of the chamber above the seal from communication with the device below the seal.

A rotor designated generally by the numeral 16 is carried on and with the upper end of the motor driven shaft 12. The outer surface of the rotor 16 is cone shaped and is adapted to rotate within the outer housing 11. The housing and the rotor carried therewithin together define a generally distended chamber for the body of water which has its temperature and pressure materially raised by subjecting it to shock waves. A water inlet 17 is provided in the housing cap 11d and is the means for delivering water to the distended chamber within the housing 11 and in and around the rotor 16. The chamber is defined as distended because it is not just an open one part chamber but rather is broken up into many small passageways which project in many directions. Webster's defines "distend" as "to stretch out or extend in more than one diection." The water body chamber includes a horizontally disposed ring shaped passage 18 located between the housing under cap 11d and the rotor 16. The rotor is vertically spaced above the housing on its underside to define the ring shaped passage 18. The water inlet 17 directly communicates with the ring shaped passageway 18 as best shown in FIG. 1. An upwardly and outwardly flaring annular cone shaped passageway 19 is located between the housing body portion 11a and the rotor 16. Again, there is a spacing between these elements to define the cone shaped passageway 19. A plurality of radially inwardly extending arcuately spaced apart passageways 20 are adapted to pass through a portion of the rotor 16. At their outer ends these passages 20 join the cone shaped passageway 19. An inwardly inclined conical shaped passageway 21 is concentrically disposed radially inwardly of the conical shaped passageway 19. The inner ends of each of the plurality of horizontal passageways 20 run directly into the conical shaped passageway 21. This joining of the many passhaped passageways is shown in FIG. 1 and further in the sectional view of FIG. 2. A radially inwardly extending ring shaped passageway 22 is provided near the bottom of the rotor and joins the lower end of the conical

shaped inner passageway 21. The inner end of the ring shaped passageway 22 enters a vertically disposed central chamber or core 23 within the rotor 16.

The rotor 16 includes an outer cup-shaped portion 24 and a combination inner and top portion 25. This combination inner and top portion is fastened around its outer circumference by a plurality of arcuately spaced cap screws 26 to the outer body portion 24. The rotor 16 comprising the two main parts is nevertheless a unitary device rotating as one mass. The two piece construction permits the easy making of the passageways 21 and 22 and before assembly permits the drilling of the plural passageways 20 near the top of the outer cup shaped portion 24 of the rotor. Over the top of the rotating rotor there is defined a ring shaped passageway 27 beneath the upper cap member 11b. A vertically disposed cylindrical ring shaped passageway 28 has its top joining the top passageway 27 at the upper outside of the rotor 16. The outer periphery of a radially inwardly extending annular passageway 29 joins the lower end of the passageway 28 and at its inner periphery joins the upper end of the cone shaped passageway 19.

A specially constructed fitting 30 has an externally threaded portion at its lower end at 31 which is threadedly engaged with internal threads within a central opening portion of the upper cap 116 of the housing 11. This fitting 30 forms the base for a superstructure 32 disposed over the basic unit contained within the housing 11. Of course the superstructure then becomes an extension of the stationary housing 11. An outer pipe 33 has its lower end threadedly engaging the upper end of the special fitting 30 at 34. A special cap fitting 35 threadedly engages the upper end of the outer pipe 33 as shown at 36. An inner concentric pipe 37 and a radially inwardly projecting annular flange 38 of the cap fitting 35 are joined to one another by a threaded engagement as shown at 39. The juncture 39 is located at an intermediate position between the top and bottom of the vertically disposed inner concentric pipe 37.

An adjustable value 40 is provided on the top of the inner pipe 37 to control the discharge of steam as the steam is generated in the device of this invention. The valve 40 is threadedly engaged at 41 to the pipe 37.

The lower end 42 of the inner pipe 37 has its outer surface milled or turned down so the pipe wall is relatively thin and thus may be assembled with the other concentric members by passing downwardly through the internal threads on the annular flange 38. An intermediate concentric pipe 43 has its upper end disposed between the cap fitting 35 and the inner pipe 37. The upper end of the intermediate pipe 43 stops short of contact with the underside of the flange 38, leaving a space 44 thereover.

An annular flange 45 is provided intermediate the top and bottom of the special fitting 30. External threads are provided on the intermediate pipe 43 near its bottom and these threads cooperatively engage with internal threads on the inner aperture of the special fitting flange 45 as shown at 46. The pipe 43 includes a lower extension 47 which has its surface milled or turned down to permit it to pass by the threads 46 on the flange 45 during assembly. This is similar to the turning down of the lower extension of the inner pipe 37.

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The intermediate inwardly extending annular flange 45 of the fitting 30 is provided with a plurality of arcuately spaced apart vertically disposed holes 48. These holes constitute restricted passageways of the water in the steam generator of this invention from the lower chamber 49 defined by the fitting 30 to an upper portion or chamber 50 defined above the annular flange 45 and between the intermediate pipe 43 and the outer pipe 33. The upper limits of the chamber 50 are defined by the inner and underside of the special cap fitting 35.

A thin annular chamber 51 is disposed between the cap 35 and the intermediate pipe 43. A second thin elongated annular chamber 52 is concentric with the chamber 51 and is located between the intermediate pipe 43 and the lower end 42 of the inner concentric pipe 37. By reason of the space 44 over the top of the intermediate pipe 43 the thin annular chambers 51 and 52 are joined one to the other. The elongated annular passageway 52 is provided with an annular opening 53 located at the bottom of the lower extension 42 of the inner concentric pipe 37. A central passageway 54 is provided within the inner pipe 37 and is utilized to carry generated steam to the controlling valve 40 at the top thereof.

OPERATION OF THE DEVICE OF FIG. 1

To commence operation, water under normal line pressures is admitted to the inlet pipe or fitting 17 so that water flows in the direction of the arrow 55 to the distended or tortuous path chamber which comprises a single body of water. The arrow 56 shows movement of water from the inlet 17 through the annular passageway 18 and to the cone shaped passageway 19 where the water proceeds upwardly in the direction of the arrow 57. From there the water enters the several radial holes 20 and moves in the direction of the arrow 58 to the inner cone shaped passageway 21 where the water moves downwardly in the direction of the arrow 59. The passageway 21 is joined at its bottom to the annular ring shaped passageway 22 and as shown by the arrow 60 water moves radially inwardly to the central passage 23 within the rotor 16. The water then proceeds upwardly as indicated by the arrows 61. Here the water enters the special fitting lower chamber 49 and as indicated by the arrow 62 moves upwardly therethrough into the restricted apertures 48 and continues upwardly through such vertically disposed apertures as indicated by the arrow 63. At this point the water enters the annular chamber 50 and moves upwardly therethrough as indicated by the arrows 64. The upper end of the chamber 50 joins the thin annular ring shaped chamber 51 and as indicated the water moves further upwardly in the direction of the arrows 65 to the space 44 just beneath the annular flange 38 of the special cap 35. Now the water changes its direction of flow and starts moving down and through the thin annular ring shaped chamber 52 in the direction of the arrows 66. In addition to the water moving vertically into the chamber 62 a portion thereof moves radially outwardly through the passageway 27 in the direction of the arrows 67. At the outer end of the ring shaped passageway the water moves down the vertical ring shaped annular passageway 28 in the direction of the arrow 68. Now the water travels radially inwardly through the ring shaped horizontal disposed annular passageway 29 in the direction of the arrow 69 and hence back to the

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outer conical shaped passageway 19 between the rotor 16 and the main body portion 11a of the housing 11.

Water now fills the entire distended chamber which as explained contains numerous passageways forming a tortuous path and providing a cycle for the movement of water therethrough. Prior to the complete filling of the system with water, rotation of the shaft is commenced. The shaft 12 is rotated by coupling a motor thereto and the rotor 16 with its several unitary parts 24, 25 and 26, is rotated at a relatively high speed causing the water to be thrown centrifugally outwardly within the chamber through any passageway thereof having a radial disposition or a radial component. The large horizontally disposed ring shaped annular passageway 27 is one such radial passageway. This immediately results in water being drawn downwardly out of the closed bottom passageway comprising the chambers and passageways 49, 50, 51 and 52. The water suddenly and positively pulled downwardly from this closed bottom channel creates a vacuum in the bottom of this channel which in the device of FIG. 1 is at the top of the stationary superstructure at the space 44. This newly created vacuum now sets up a pull of its own which exceeds and overcomes the centrifugal forces and the body of water comes back into the bottom of the closed bottom channel with a snapping action. This sudden striking of the closed bottom extinguishes movement of the column of water and there is a substantial shock imparted to and within the body of water. This water hammer or shock brings with it a rise in pressure and temperature of the body of liquid. In Horace King's "Handbook of Hydraulics" published by McGraw-Hill, 4th Edition, page 6–21 there is a discussion of water hammer and its creation. The King handbook states that if a passageway in a pipe line is suddenly closed (corresponding to the closed bottom channel in applicant's device),

"a dynamic pressure, in addition to the normal static pressure, is created within the pipe. This dynamic pressure is commonly called water hammer. It is caused by the sudden transformation of kinetic energy to pressure energy." J. N. Bradley's "Shockwaves in Chemistry and Physics" discusses The Measurement of Thermodynamic Quantities in Chapter V. Page 172 of that book and states that

". . . a shock wave in a liquid medium is characterized by a small rise in temperature and an extremely large change in pressure." Applicant is thus intentionally creating shock waves in this distended body of water causing both temperature and pressure rises. Although the temperature rise created by each shock is small, the shocks are repeated over and over again, one upon the other, and thereby intensified causing a material rise in temperature of the entire body of water. Each shock caused by the sudden extinguishment of flow of water at the dead ended channel creates a force of approximately 63.4 pounds per square inch of every foot of extinguished velocity. Although this degree of pressure is only held momentarily the succeeding shock waves are cumulative and although the pressure dissipates throughout the body of water the temperature rises materially and is not so easily dissipated as the pressure. The rise in temperature and the maintenance of that temperature rise is so spectacular that steam is almost instantaneously created and starts up the pipe 37 through its center passage 54 in the direction of the arrows 70. Unconverted steam in the form of water in

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various stages of heat is pulled downwardly in the direction of the arrows 71 whereupon the cycle is repeated with the rapidly increasing shock waves causing the water to be more easily converted to steam and that steam being discharged upwardly in the direction of the arrows 70 and thence through the adjustable valve 40. Of course, water is always being admitted to the inlet 17 to keep the system full and constantly replenish that portion of the water that has been converted to steam and has been discharged through the valve 40 for some external use.

The modified or alternative construction of FIG. 5 is similar to the preferred device of FIG. 1, but is shown primarily to emphasize that various body chambers may be employed. As explained for the device of FIG. 1 the water chamber is distended in nature — not any particular shape — but expressly including one or more closed bottom channels within which a vacuum may be drawn and at least one or more radial passages or passages with radial components to produce a centrifugal action. The steam generator of FIG. 5 is generally designated by the numeral 80. The generator is provided with a stationary housing 81. The housing comprises a main body portion 81a, an upper cap 81b fastened to the central body portion 81a by a circularly arranged series of arcuately spaced apart cap screws 81c, an under cap 81d fastened to the body portion 81a by a circularly arranged series of arcuately spaced apart cap screws 81e, a downwardly projecting central tubular portion 81f forming a part of the under cap 81d, and a bottom cover 81g fastened by a series of circularly arranged arcuately spaced apart cap screws 81h to the central tubular portion 81f.

A vertically disposed motor driven shaft 82 having an annular shoulder 83 therearound is journally carried within the central tubular portion 81f of the housing 81 by means of a roller bearing 84. The inner race of the bearing 84 is disposed in a vertical position between the annular shoulder 83 of the rotating shaft 82 at its top and the stationary cover 81ig at its bottom. An annular seal 85 is held within the housing 81 and brushes against the rotating shaft 82 to effect a sealing of the chamber above the seal from communication with the device below the seal.

A rotor, conical in overall shape, is designated generally by the numeral 86. The rotor is carried on and with the upper end of the motor driven shaft 82. The rotor 86 is adapted to rotate within the outer housing 81. The housing and the rotor carried therewithin together define a generally distended chamber for the body of water which has its temperature and pressure materially raised by subjecting it to shock waves. A water inlet 87 is provided in the housing cap 81d and is the means for delivering water to the distended chamber within the housing 81 and in and around the rotor 86. The chamber is defined as distended for the same reasons as applied to the chamber in the device of FIG. 1. The water body chamber includes a horizontally disposed ring shaped annular passage 88 located between the housing under cap 81d and the rotor 86. The rotor is vertically spaced above the housing on its underside to define the ring shaped annular passage 88. The water inlet 87 directly communicates with the ring shaped passageway 88 as best shown in FIG. 5. An upwardly and outwardly flaring annular cone shaped passageway 89 is located in the space between the housing body portion 81a and the rotor 86. A plurality of radially in-

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wardly extending arcuately spaced apart passageways 90 are adapted to pass through a portion of the rotor 86. At their outer ends these hole like passages 90 join the cone shaped passageway 89. An inwardly inclined conical shaped passageway 91 is concentrically disposed radially inwardly of the conical shaped passageway 89. The inner ends of each of the plurality of horizontal passageways 90 run directly into the conical shaped passageway 91. This joining of the many passageways is shown in FIG. 5 and further in the sectional view of FIG. 6. The inner cone shaped passageway 91 forms one of the closed bottom passageways of this distended chamber of the device of FIG. 5.

The rotor 86 includes an outer cup-shaped member 92, an intermediate member 93 generally nesting within the cup portion 92 and a circular or disc shaped cap member 94. A plurality of arcuately spaced apart cap screws 95 define an outer ring around the cap 94 and constitute the means of joining the cap 94 to the outer portion 92 of the rotor 86. A plurality of similar arcuately spaced apart cap screws 96 define an inner ring around the cap for joining the cap 94 to the intermediate portion 93 of the rotor 86. These three body members with their cap screws 95 and 96 together constitute a unitary rotor which rotates within the stationary housing 81 and thereby creates the shock waves for effecting the rise in the temperature of the distended body of water to generate steam.

The rotor 86 includes an annular ring shaped passage 97 disposed between the intermediate portion 93 and the cap 94. The top of the outer annular portion of the intermediate portion 93 is milled or turned down to provide the space for the annular passageway 97. The rotor also includes a plurality of arcuately spaced apart vertically disposed closed bottom channels 98. The arrangement of these holes or channels 98 is in a circular path which is generally arranged concentric to the center of the composite rotor. The inner annular surface 99 of the top of the intermediate portion of the rotor has not been milled down and thus having its full height closely abuts the underside of the cap 94. Thus when the cap screws 96 are drawn up tightly the unmilled central ring portion 99 of the member 93 acts as a spacer for the remainder of the top of that member from the underside of the cap 94. This clearly defines the radial passageway 97 which joins the inner cone shaped passageway 91 with the open topped closed bottom holes 98. The rotor is further provided with a central vertically disposed passageway 100 about it vertical centerline. At the juncture of the bottom center of the intermediate member 93 of the rotor with the bottom of the cup shaped outer member 92 of the rotor the central passageway 100 is enlarged as shown at 101. A plurality of relatively small diameter radially disposed holes or passageways 102 join each of said closed bottom channels 98 with the enlarged chamber 101 at the center of the rotor. These radial passageways 102 are disposed at a position spaced above the closed bottoms of the holes 98. It is generally through these minute relief holes 102 that generated steam is permitted access to the center of the rotor where it moves upwardly through the passage 100 and thence into an enlarged steam passageway 103 located above the channel 100. Steam may be permitted free escape from this passageway 103 or may be selectively discharged by a suitable adjustable valve means such as that shown at 40 in FIG. 1.

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OPERATION OF THE DEVICE OF FIG. 5

As for the steam generator of FIG. 1 water is admitted to the system of FIG. 5 by passing through the inlet 87 in the direction of the arrows 104. The water then moves in the annular ring shaped passageway 88 in the direction of the arrows 105 to the juncture with the cone shaped passageway 89. The water now moves upwardly in the direction of the arrows 106 to the juncture of the full annular passageway 89 with the plural radial passages 90. Water then moves inwardly in the direction of the arrows 107. As previously stated, an inner concentric cone shaped passageway 91 joins these several radial holes 90 and thus the incoming water fills that passageway as shown by the arrows 108. As the ring shaped bottom of the passage 91 is effectively closed the water then moves radially inwardly across the top of the outer portion of the intermediate member 93 of the rotor in the passageway 97 as shown by the arrows 109. Here the inner circumference of the annular ring shaped passageway 97 joins with the tops of the plural closed bottom passages 98 and incoming water then moves down these holes as shown by the arrows 110 to thus fill the entire distended chamber formed by this maze of multi-directional passageways. Most of the arrows just described for the movement of water in the various chambers and passageways are two headed indicating that water during the operation of the device moves in both directions.

Prior to the system being completely filled with water, rotational drive is imparted to the shaft 82 and thereupon its integral rotor 86 is also rotated. Rotation is at relatively high speeds. The initial response to the body of water is its centrifugal action through all radial passageways and passageways having radial components. In this device the primary centrifugal action is created in the elongated radially outwardly extending annular ring shaped horizontally disposed passageway 97. The imposition of this force in the body of water causes the columns of water in the multiple closed ended channels 98 within the rotor to be drawn upwardly out of their closed bottoms.

Almost immediately there is a multiplicity of vacuums created in each closed bottom with the result that the vacuums overcome and exceed the opposite force of centrifugal action to thereby cause the columns of water to snap back into the closed bottoms of these channels. As previously explained for the operation of the device of FIG. 1 the extinguishment of the motion of the body of water by the closed bottoms of the channels imposes shock waves in the distended body of water so that there is an incremental increase in both temperature and pressure of the body of water. The repeated and continuous rotation of the rotor causes multiple shock waves or water hammer and actually an intensification of the shocks when they are occasioned one upon the other. Thus what would have been only a small rise in temperature is now substantial. The pressures similarly rise but they quickly dissipate in the system. The water commences its conversion to steam generally in the area of the closed bottoms of the channels 98 where the greatest effect of the snap action shocks takes place. This newly created steam is permitted to escape radially inwardly through the restricted holes 102 in the direction of the arrows 111. Once in the central chambers of the rotor the steam moves ver-

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tically upwardly through the successive passages 101, 100 and 103 as indicated by the arrows 112.

Both the devices of FIGS. 1 and 5 act to generate steam. Their common attributes are their stationary housings with rotors therein which together define distended chambers with tortuous passageways and at least one closed bottom passageway and a passageway permitting centrifugal action to create forces in the body of water opposite to the vacuum created forces in the closed bottom channels. In FIG. 1 the closed bottom channel is located in the stationary housing portion of the device whereas in FIG. 5 the closed bottom channels are located in the moving rotor. It is thus apparent that the steam generator of this invention may take many and varied forms without departing from the principles disclosed herein. Thus it is not my intention to limit the patent granted hereon otherwise than as necessitated by the appended claims.

What is claimed is:

1. A steam generator comprising a stationary housing, a rotor journally mounted for rotation within said stationary housing, said housing and rotor together defining a distended chamber, means delivering water to said distended chamber, at least one portion of said distended chamber comprising a closed end passageway and at least another portion of said distended chamber comprising another passageway capable of being subjected to centrifugal force, means rotating said rotor when the distended chamber has water therein whereby such rotation creates shock waves in the body of water in said distended chamber by reason of centrifugal action occurring in said another passageway and a vacuum occurring in the closed end passageway and the two forces alternately conflicting and overcoming one another to produce and intensify shocks in said body of water to thereby cause a substantial rise in temperature and pressure of the body of water, thereby converting a portion of said body of water to steam, and means for removing steam created in the body of water.

2. A steam generator as defined in claim 1 in which said rotor is generally cone shaped on its outer surface and the distended chamber comprises a series of generally narrow passageways joined in a multi-directional manner.

3. A steam generator as defined in claim 1 in which said closed end passageway is disposed in the stationary housing.

4. A steam generator as defined in claim 1 in which said closed end passageway is disposed in the rotor.

5. A steam generator as defined in claim 1 in which said stationary housing includes a superstructure offset from said portion housing said rotor.

6. A steam generator as defined in claim 5 in which said superstructure comprises a plurality of concentric pipe members and wherein the closed end passageway comprises concentric thin annular ring shaped passageways at one end of said superstructure.

7. A steam generator as defined in claim 6 in which said superstructure of concentric pipes includes a series of alternately large and smaller passageways.

8. A steam generator as defined in claim 2 in which there is included a first thin cone shaped annular passageway disposed between the stationary housing and the rotor, a second thin cone shaped annular passageway disposed within said rotor and generally concentric to said first of said cone shaped passageways, and a plu-

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rality of arcuately spaced apart radially disposed passages in said rotor joining said first and second cone shaped passageways.

9. A steam generator as set forth in claim 8 in which there is included a central vertically disposed passageway within said rotor and a radially disposed passageway communicating between said second cone shaped passageway and said central vertically disposed passageway within said rotor.

10. A steam generator as set forth in claim 8 in which there is included a central vertically disposed passageway within said rotor, and said radially directed passageway communicating with at least one of said cone shaped passageways and directly communicating with said closed end passageway, and means discharging steam converted from said water to the central vertically disposed passageway within said rotor.

11. A steam generator as set forth in claim 10 in which said means discharging steam comprises an auxiliary passageway from said closed end channel to said central vertically disposed passageway in said rotor.

12. A steam generator as set forth in claim 8 in which the closed end passageway includes a plurality of generally vertically disposed closed bottom holes in said rotor and arranged in arcuately spaced apart position to define a generally circular path, said rotor having a central passageway, said series of passageways including radial passageways joining said second thin cone shaped passageway and the tops of said plurality of generally vertically disposed closed bottom holes, and restricted passageways joining said central passageway

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and each of said plurality of closed bottom holes intermediate their tops and bottoms, whereby steam is permitted to escape radially inwardly through said restricted passageways to said central rotor passageway.

13. A steam generator comprising a stationary housing, a cone shaped rotor journally mounted for rotation within said stationary housing, said housing and rotor together defining a distended multi-passageway chamber, means delivering water to said distended chamber, at least one passageway of said distended chamber having a closed end, and at least another passageway of said distended chamber having a radial component, means rotating said cone shaped rotor when the distended chamber has water therein whereby such rotation creates water hammer shock waves in the body of water in said distended chamber by reason of the centrifugal action created in said radial component passageway and the vacuum created by the closed end passageway causing the movement of water in that passageway to be suddenly extinguished, and the alternating of the centrifugal action and the vacuum continuing to create shocks and cause a rise in temperature and pressure of the body of water, and means for removing steam created in the body of water.

14. A steam generator as defined in claim 13 in which said closed end passageway comprises an annular ring shaped passageway in said stationary housing.

15. A steam generator as defined in claim 13 in which said closed end passageway comprises a plurality of vertically disposed closed bottom holes in said rotor.

* * * * *

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United States Patent [19]

Leibow et al.

[11] **4,208,592**

[45] **Jun. 17, 1980**

[54] **COMPRESSED AIR POWER GENERATING SYSTEM**

[76] Inventors: Baruch Leibow; Isaac Leibow, both of Hashilowach St., #16, Haifa, Israel

[21] Appl. No.: **940,378**

[22] Filed: **Sep. 7, 1978**

[51] Int. Cl.² H02K 7/18
[52] U.S. Cl. 290/52; 60/407; 322/35; 417/411
[58] Field of Search 290/52, 54, 43, 44; 322/35, 38, 40; 60/407, 412, 410, 419; 417/411

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[57] **ABSTRACT**

A system for converting compressed air to motive power for generating electricity, a part of the output being used to partially recharge an initial compressed air source, thereby permitting the device to operate for extended periods without an external source of energy.
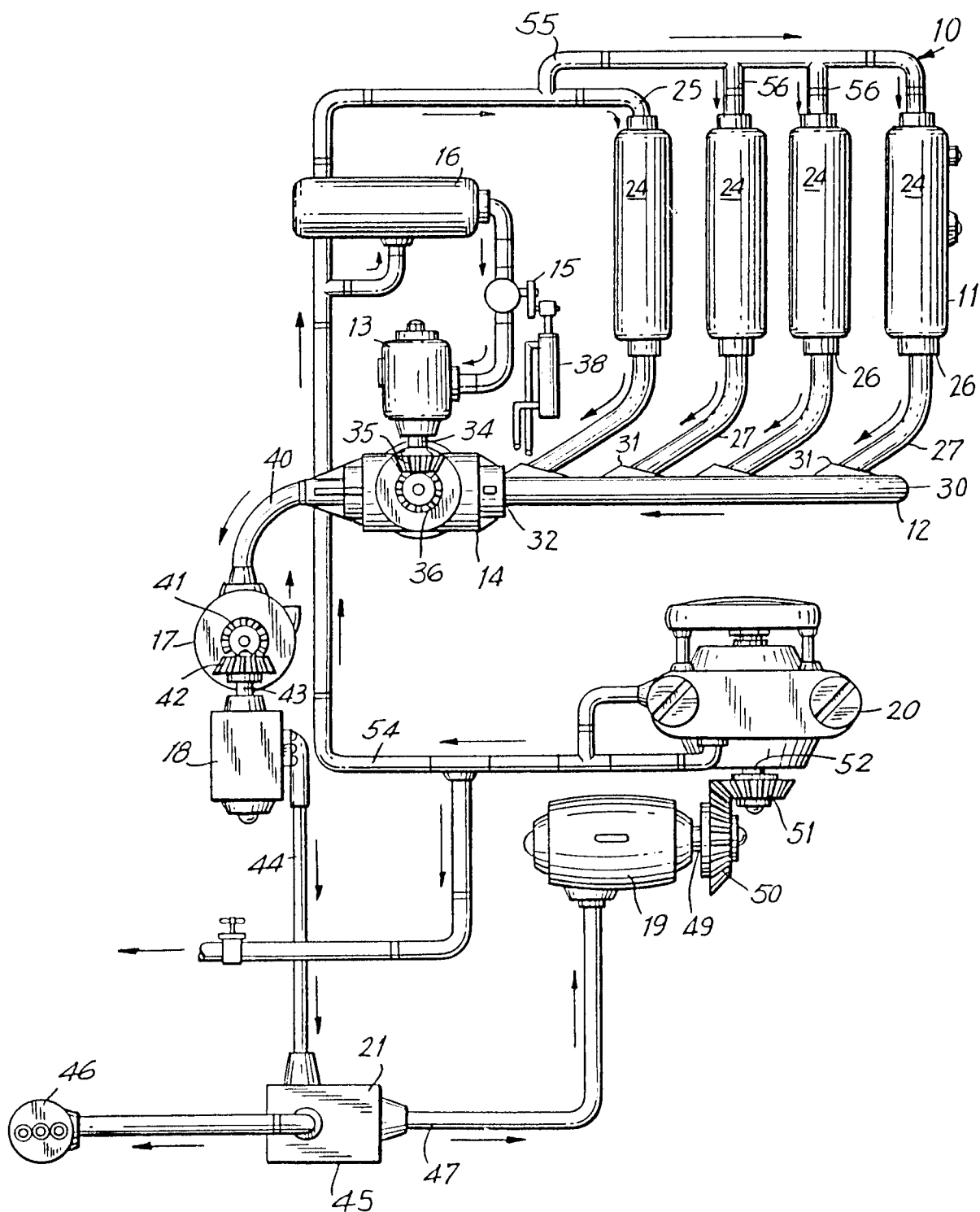
3 Claims, 1 Drawing Figure

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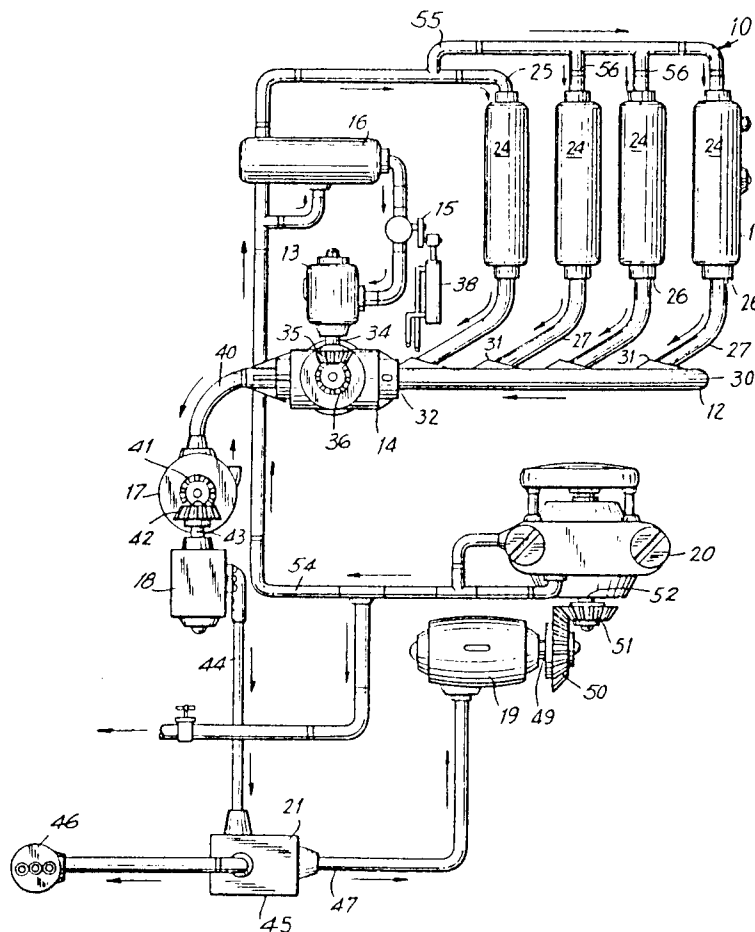
COMPRESSED AIR POWER GENERATING SYSTEM

BACKGROUND OF THE INVENTION

This invention relates generally to the field of electric power generation, and more particularly to an improved form of small generating plant adapted to operate for relatively extended periods of time in the order of several hours without other than an initial charge of compressed air as an energy source. Such devices are particularly useful in specialized applications where petroleum fuels and the like are not readily available or usable.

Motors and turbines operating from power generated by expanding gasses are well known in the art, such devices normally employing combustible fuels in either liquid or gaseous form. The use of compressed air motors for a variety of functions is also known.

Where a constant energy source is continuously supplying a compressed or expanding gas under pressure, continuous operation may be maintained without difficulty. However, when only a fixed individual charge of such gas is available, a constant diminution in pressure soon makes continuous operation of such devices impossible.

SUMMARY OF THE INVENTION

Briefly stated, the invention contemplates the provision of a compressed air system capable of generating electricity for extended periods of time using an initial charge of compressed air which is utilized in such manner that the devices using such compressed air ultimately compress small amounts of air under high pressure which is returned to the initial source, thus maintaining operational pressure for a longer period of time than would otherwise be the case. Devices of this type have application in specialized situations where the use of combustible fuels is not possible, but the requirement for continuous generated power is substantially greater from a time standpoint than is normally available from a fixed charge compressed air source.

BRIEF DESCRIPTION OF THE DRAWING

In the drawing, to which reference will be made in the specification, the FIGURE is a fragmentary schematic view of an embodiment of the invention.

DETAILED DESCRIPTION OF THE DISCLOSED EMBODIMENT

In accordance with the invention, the device, generally indicated by reference character 10, comprises broadly: a rechargeable source of compressed air 11, a compressed air manifold element 12, an air powered stand element 13, an air regulating sprayer element 14, air valve means 15, an auxiliary cylinder element 16, an air turbine element 17, an electrogenerator 18, an electromotor 19, a compressor element 20 and a power output junction 21.

The chargeable source 11 includes a plurality of air cylinders 24 having charging inlets 25 and exhaust outlets 26 including conduits 27 feeding the manifold 12.

The manifold 12 includes a closed end 30, a plurality of inlet connections 31, and a single outlet 32 leading to the sprayer element 14.

The stand element 13 includes an air motor (not shown) having an output shaft 34 mounting a bevel gear 35 which drives a corresponding bevel gear 36 on the

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sprayer element 14. The motor is powered from the auxiliary cylinder element 16 and controlled by the valve means 15 by means of a small air cylinder 38 and associated linkage. Means (not shown) controls the cylinder 38 such that with diminution of pressure in the source 11, more air is fed from the auxiliary cylinder element 16 to enable the sprayer to distribute a greater flow of air to the turbine 17, thereby maintaining a constant angular velocity in the latter.

Extending from the sprayer element 14 is a conduit 40 leading directly to the turbine 17. The turbine drives through bevel gears 41 and 42 a shaft 43 on the generator 18, the output of the same flowing over leads 44 to a junction box 45 having a power outlet 46. Another set of leads 47 leads to the motor 19, the output shaft 49 of which drives through bevel gears 50 and 51 and input shaft 52 of the compressor 20. The compressor 20 is in the form of a positive displacement blower, and delivers a relatively small volume of air at a pressure substantially higher than the initial pressure in the source 11. The output of the compressor is fed over conduits 54 and 55 to a return conduit 56 servicing the charging inlets 25 of the source 11.

OPERATION

To commence operation, the cylinders comprising the source 11 are charged to approximately 12 atmospheres pressure. It is to be noted that the stand is separately driven by auxiliary cylinders and may operate on considerably lower pressure. The individual cylinders of the source 11 may be drained either serially, or in parallel, and in either event is regulated such that when pressure is relatively high, the air reaching the turbine is forced to move through more constricted passages. As pressure drops, the sprayer rotates more rapidly, enabling the air to more readily reach the turbine, thereby maintaining substantially constant velocity necessary to maintain a correspondingly constant output from the generator.

During operation, compressed air is continuously being supplied to the source 11 from the compressor, although it will be readily appreciated that because of the reduced volume available from the compressor, the pressure in the source will be continuously diminished, although at a much lower rate than would be the case if no replenishment of compressed air were available. During operation, a continuous flow of electrical energy may be drained from the junction box, and power output remains substantially constant, until the pressure in the source drops below that necessary to sustain operation of the turbine. Where roughly $\frac{1}{3}$ of the available energy from the generator is extracted, the system can sustain itself for more than three hours of continuous operation. It can be recommenced by recharging the source 11 to its initial pressure.

To obtain the equivalent amount of operating time without partially restoring pressure in the source, the source itself would need to be many times larger than is otherwise necessary, and since pressure drop during operation would not be in a straight line, but a continuously diminishing curve, proper operation would be impossible while less than half of the available volume in the source is consumed.

I wish it to be understood that I do not consider the invention limited to the precise details of structure shown and set forth in this specification, for obvious

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modifications will occur to those skilled in the art to which the invention pertains.

I claim:

1. An improved compressed air generating system comprising: a chargeable source of compressed air, air motor means driven from said chargeable source, means for regulating the flow of air from said source to said motor means for automatically maintaining substantially constant speed of said motor means during changes in pressure in said source, generator means driven by said air motor means, means for utilizing part of the electrical energy generated by said generator means for external power, an electromotor driven by a remaining part of said electrical energy, air compressor

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means driven by said electromotor, and means conducting the output of said air compressor means to said chargeable source.

2. A system in accordance with claim 1, further characterized in said air motor means being in the form of a turbine, and said regulating means being in the form of a rotary air sprayer in series with the flow of compressed air to said turbine, and sensitive to varying pressure in said chargeable source.

3. A system in accordance with claim 1, further characterized in said air compressor producing compressed air at a pressure above that in said chargeable source.

* * * * *

July 26, 1960   G. JENDRASSIK   2,946,184

PRESSURE EXCHANGERS AND APPLICATIONS THEREOF

Filed Nov. 5, 1952   3 Sheets—Sheet 1

FIG. 1.

FIG. 2.

FIG. 4.

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FIG.3.

FIG.5.

FIG.5A.

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PRESSURE EXCHANGERS AND APPLICATIONS THEREOF

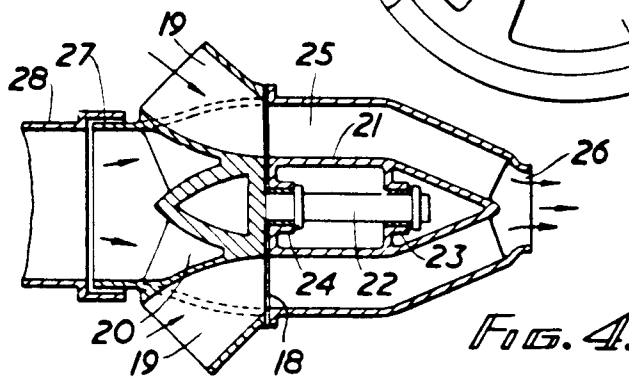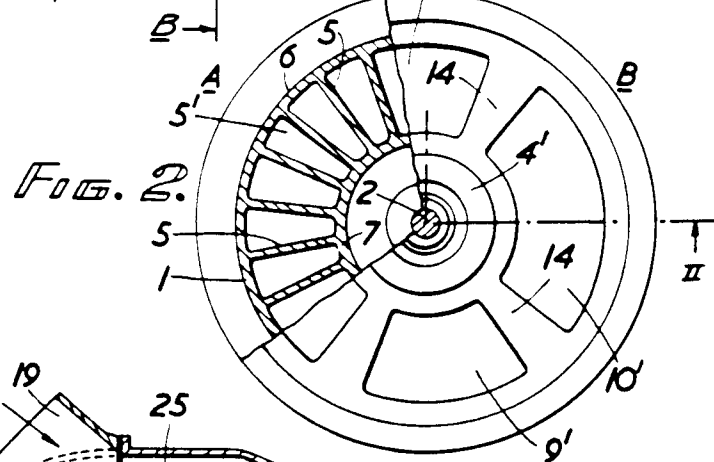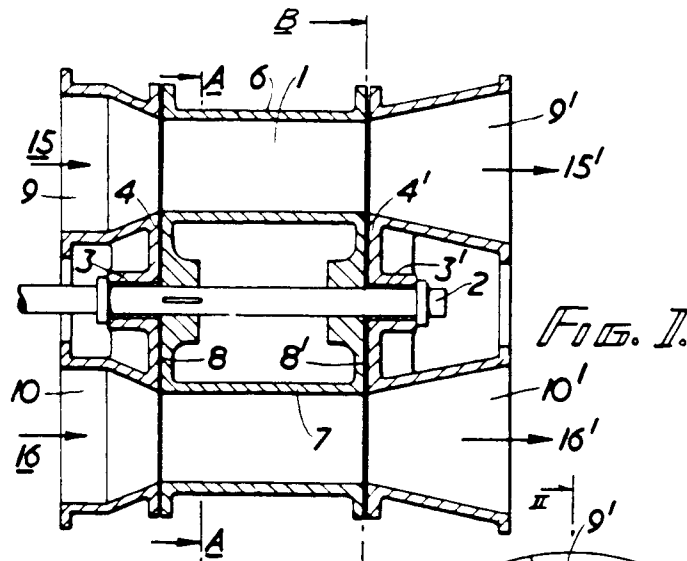Filed Nov. 5, 1952   3 Sheets—Sheet 3

FIG.6.

FIG.7.

FIG.8.

FIG.9.

FIG.10.
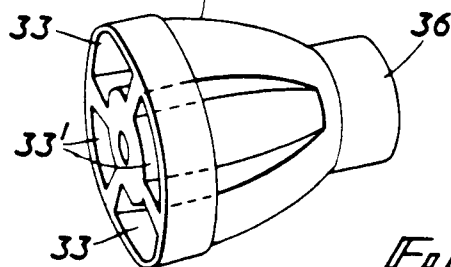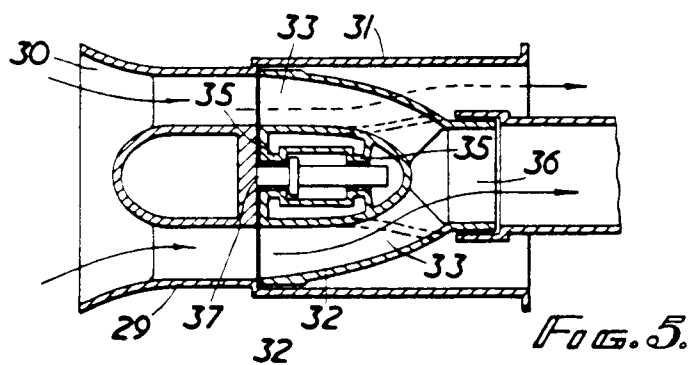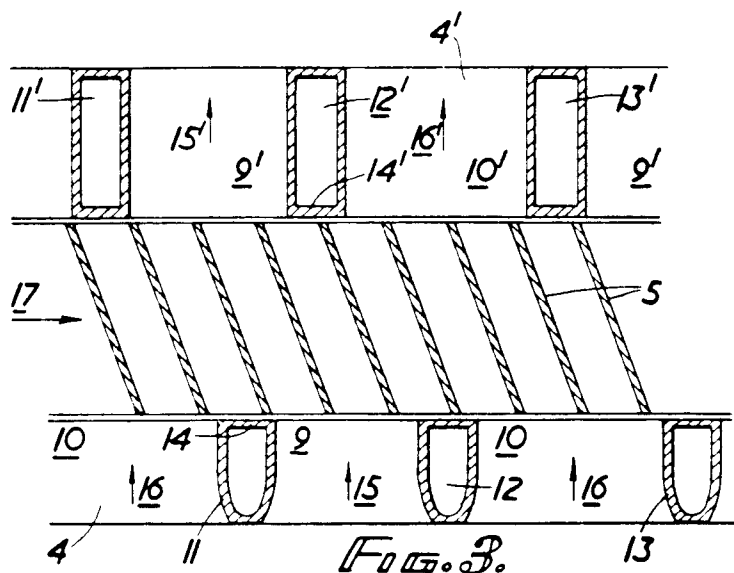
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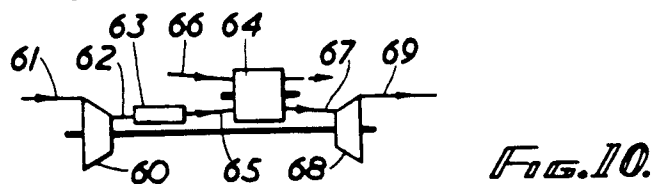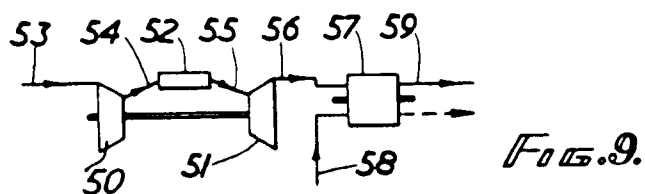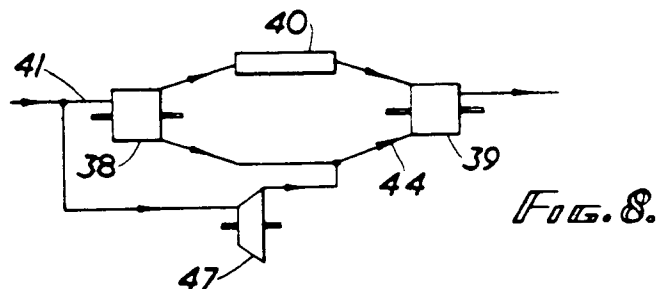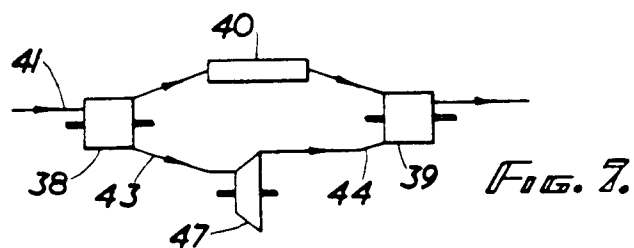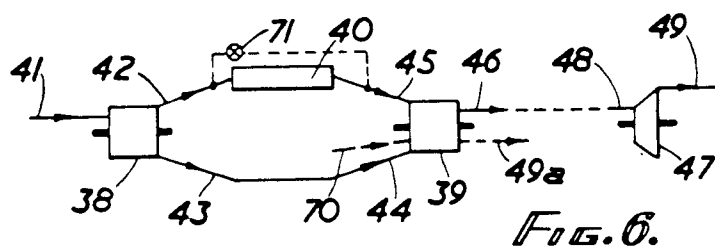
By _____
  Attorneys

United States Patent Office

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This invention relates to pressure exchangers and to applications thereof. Pressure exchangers have been previously proposed in which work is transmitted from a fluid of higher pressure level to a fluid at a lower pressure level. Suggested apparatus for this purpose has comprised a cell wheel with end plates adjacent the ends thereof through which fluid is delivered to and discharged from the cells. In such apparatus the cell wheel and end plates are relatively rotatable. In one proposed pressure exchanger the transmission of work capacity was to be performed by fluid pressure impulses within the cells whilst in others the expansion of fluid from one cell effected compression of fluid in another. Scavenging through the cells at one stage of operation is a common expedient.

The present invention provides a pressure exchanger comprising a number of cells each of which is placed in communication at its ends with fluids at different pressure levels so that there is at such times a pressure difference between the two ends of the cell and so that, by acceleration and deceleration of fluid within the cells, work is transmitted between fluid communicating with the pressure exchanger at the different pressure levels.

The cells of such a pressure exchanger may conveniently be arranged annularly around the periphery of a cell wheel which is rotatable relatively to an adjacent end plate. Through that end plate the cells may have access to a plurality of ducts circumferentially spaced relative to the axis of rotation, through which fluids at different pressure levels are delivered to the cells. At the other end of the cells from that end plate communication may be obtained to one or more ducts maintained at pressure levels different from those of the delivered fluid; a similarly arranged end plate may be incorporated at this other end also. The width of the duct passages through an end plate and their mutual relationship are preferably arranged so that in a normal operation most advantageous use is made of acceleration and deceleration impulses caused in the fluid within a cell as the latter moves relatively to the duct passages.

A pressure exchanger according to the invention is stated above to have in operation a pressure difference between the two ends of a cell. In certain instances it is convenient to transform a fluid pressure into a velocity component, for example one end of a cell may be deliberately made convergent in cross sectional area so that fluid is discharged therethrough at a higher speed than it otherwise would be. Such an increase in velocity at the expense of fluid pressure and similar transformations are intended to be maintained within the scope of the invention.

The present invention further provides a pressure exchanger comprising a number of cells each of which in turn is placed in communication at one end with fluid at two different pressure levels alternatively and at its opposite end only with fluid at a pressure level between said different pressure levels.

As an extension of the latter pressure exchanger each

of the cells at its said one end may be placed in communication with a plurality of fluid sources at different pressure levels in succession and at its opposite end only with fluid at a pressure level intermediate between the extremes of said pressure levels.

According to the invention there is provided a pressure exchanger which is arranged substantially to equalize the pressure of fluids at a plurality of pressure levels comprising a cell wheel, and end plate adjacent thereto, means for effecting relative rotation between the cell wheel and the end plate, a plurality of ducts through each of which one of said different pressure fluids is conveyed to the end plate for delivery to the cell wheel, the arrangement being such that every cell in turn is placed in communication at one end with said ducts in succession, and a common duct whose internal pressure is maintained at a level intermediate between the extreme pressures of said delivered fluids into which fluid is discharged from the other end of the cells.

The latter is a special form of pressure exchanger, that is one which receives fluids at different pressure levels and in effect discharges fluid at an intermediate pressure level, this apparatus may be termed a pressure equalizer.

The invention also provides a pressure exchanger which is arranged to produce from a fluid delivered thereto supplies a fluid at a plurality of pressure levels, at least one being higher and another lower than the pressure of said delivered fluid, comprising a cell wheel, an end plate adjacent thereto, means for effecting relative rotation between cell wheel and end plate, a duct through which said delivered fluid is passed to one end of every cell and a plurality of ducts extending downstream of the cell wheel from the end plate each of which ducts is maintained at a different internal pressure level at least one being higher and another lower than the pressure of said delivered fluid and into which ducts fluid is discharged from the other end of the cells.

The latter is another special form of pressure exchanger, that is one in which delivered fluid transmits work to fluid leaving at a higher pressure, further fluid leaving at a lower pressure. This form of pressure exchanger may be termed a pressure divider.

Pressure exchangers according to the present invention have several distinguishing features from those according to the prior art. For instance embodiments of the present invention function as a result of practically continuous presence of acceleration or decleration fluid pressure impulses within any cell. There is no appreciable cell scavenging taking place at any stage in the operation of the apparatus. Moreover the prior proposals have been always for pressure exchangers forming the major part of either a heat engine or a heat pump. It has been a common factor of previously suggested pressure exchangers for fluid extracted from the cell wheel of the exchanger to be reintroduced, e.g. after heating, into the cell wheel. This feature is not present in embodiments of the present invention.

In this case, as with the prior art, the fluids between which work is transmitted are most conveniently in gaseous state. However pressure exchangers according to the present invention are not exclusively intended to operate upon gases, liquids may also be employed and it is possible to envisage embodiments intended for work transmission between liquid and gaseous fluids.

Pressure exchangers as now set forth have many applications, particularly as components of heat engine plant. The present invention provides a heat engine comprising a first pressure exchanger receiving gas at a first pressure level and discharging said gas at two pressure levels one higher and the other lower than said first level, a gas heating system receiving gas at said higher pressure level from the first pressure exchanger and discharging

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hot gas and a second pressure exchanger receiving said hot gas and gas discharged at said lower pressure level from the first pressure exchanger and discharging a stream of hot gas.

The hot gas stream, the gas at the lower pressure level of the first pressure exchanger or further gas received at the first pressure level may be expanded through an expansion machine. The latter is preferably a gas turbine.

If the second pressure exchanger is arranged to receive a further gas supply at a low temperature compared with the hot gas, greater heat may be introduced via the heating system. It is possible by replacement of the heating system with an internal combustion engine to supercharge the latter.

The expanded hot gases leaving a conventional compressor-gas turbine set may conveniently be introduced into a pressure exchanger with a lower pressure gas supply. The discharged gas therefrom may then be expanded through a nozzle to produce a highly efficient propulsive thrust.

In another possible arrangement of a compressor-gas turbine set, hot gas leaving the heating system to the set is introduced into a pressure exchanger together with a lower pressure gas supply. The gas discharged from the pressure exchanger is then expanded through the turbine. By this arrangement the heating system can be allowed to introduce more heat than otherwise would be the case.

The invention will now be described with reference to certain embodiments thereof shown by way of example only in the accompanying drawings in which:

Figure 1 is a cross-sectional elevation through a pressure exchanger according to one embodiment of the invention, the upper half being a section at right angles to the lower half and shown as section II—II of Figure 2.

Figure 2 shows in its sector A a cross-section on the line AA of Figure 1 and in its sector B the face of an end plate of the same embodiment viewed at the position BB, i.e. from the right hand end of the cell wheel structure 1 of Figure 1.

Figure 3 is a peripheral development of part of the cell wheel and ducting making up the embodiment of Figure 1.

Figure 4 is a cross-sectional elevation through a second embodiment of the invention and Figure 5 shows a corresponding view of a third embodiment of the invention.

Figure 5A is a perspective view of a component of the apparatus of Figure 5.

Figures 6, 7 and 8 show three alternative ways in which pressure exchangers according to the invention can be incorporated into new heat engine arrangements in order to achieve certain desired advantages.

Figure 9 shows the incorporation of a pressure exchanger according to the present invention in a gas turbine jet propulsion engine.

Figure 10 shows an alternative arrangement of gas turbine plant lay-out in which the position of the pressure exchanger is different.

Turning first to the embodiment shown in Figures 1 to 3 there will be seen a rotary cell wheel 1 carried by a shaft 2 which is itself located in bearings 3 and 3'. The bearings are nested within end plates at opposite ends of the cell wheel as shown at 4 and 4'. The rotary cell wheel consists of a cylinder with a peripheral annulus formed between the outer wall 6 and the inner wall 7, which annulus is divided by axial/radial partitions 5 (which can best be seen in Figure 2) thus forming a number of cells 5'. The end faces 8 and 8' of the cell wheel are located closely adjacent to the respective faces of the end plates 4, 4' and sealing arrangements (not shown) are provided between the cell wheel faces and the end plates to reduce leakage losses. Such seals may take the form of labyrinth glands or sliding seals for example. They need not necessarily be on opposing

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faces in the radial plane as shown in Figure 1 but can quite well be provided on cylindrical surfaces, that is co-axial with the rotor and in some circumstances this may be preferable. In Figure 3 opportunity has been taken to show that the partitions 5 making up the cells 5' of the cell wheel need not necessarily be axial but can be inclined to the axial plane. Each end plate has ducts extending through it away from the cell wheel through which fluid is arranged to pass to and from the cell wheel. The duct passages 9, 9', 10, 10', in the end-plates are arranged in circumferentially spaced fashion around the shaft axis and are separated from one another by partitions 11, 11', 12, 12', 13, 13', shown clearly in Figure 3.

In the faces of the end-plates adjacent to the cell wheel there are sector shaped wall sections such as that shown at 14 in Figure 2 which divide the duct passages from one another. The passages themselves, such as that shown at 9, may be formed either as convergent or divergent passages as is required by the design of the pressure exchanger. In Figure 1 the arrows 15, 15', 16, 16', are intended to show the direction of flow of gas through the pressure exchanger and in Figure 3 will be seen an arrow 17 which indicates the direction of rotation of the cell wheel relative to the stationary end plates. In this embodiment it is the cell wheel that rotates but it is clearly apparent that relative rotation may be obtained between cell wheel and end plates by an arrangement of end plates which itself rotates, the cell wheel being a stationary structure. As shown in Figure 1 the rotating cell wheel mounted upon the shaft 2 may be driven by an external drive connected to the free end of the shaft.

The end plates 4 and 4' can be secured to each other as a rigid structure but they are preferably arranged relative to the cell wheel so that there is allowance for expansion. The supporting arrangement then has to be such as to permit axial displacement of the end plates relative to one another without any tilting being permitted. This is required so that the sealing system between end plates and cell wheel may be maintained. An arrangement has been previously described in U.S. Patent Application Serial No. 323,490, now U.S. Patent 2,779,530 in which the clearance gap between cell wheel and end plate is kept substantially constant in spite of thermal expansion. Use was made of bearings which are capable of taking axial thrust and are arranged closely to the clearance gap which is to be maintained. Tilting of the end plate was also prevented by the provision of guiding means which allows the end plate to be displaced in an axial direction only.

The operation of the pressure exchanger shown in the first three figures is as follows:

It will be recalled that in Figure 1 the ducts 9 and 10, and 9' and 10' are alternately arranged around the shaft axis, in fact approximately at right angles to one another as is more clearly shown in the sector B of Figure 2. The two diametrically opposite ducts 9 are bifurcated upstream of the pressure exchanger from a single duct. The same arrangement applies to the inlet passages 10. These are also bifurcated branches of a single duct. The duct leading to the inlet passages 9 communicates with the source of fluid at one pressure and the duct leading to the inlet passages 10 communicates with a source of fluid at another pressure. One of these pressures may conveniently be atmospheric pressure the fluid supplied being ambient air. The outlet passages from the pressure exchanger 9' and 10' are either each connected to sources of fluid at different pressures or are all connected to one single outlet duct downstream of the pressure exchanger. In the latter case the outlet duct is itself maintained at a pressure intermediate between the pressure levels of the two inlet fluid supplies.

It will be seen that the low pressure fluid entering the cell wheel does so by means of passages which alternate with passages for the entry of fluid at a higher pressure.

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Different pressure levels exist at the other end of the cells, e.g. two pressures between the higher and lower fluid entry pressures. Thus the cells receive impulses of high pressure fluid causing acceleration in each cell followed by periods of depression where the low pressure fluid acts on a cell thereby effecting deceleration therein. At the other end of each cell fluid contained therein is delivered to the pressure level obtaining in the adjacent duct passage, the entering fluid of higher pressure in effect pumping or compressing the entering fluid of lower pressure which also enters, to the two leaving pressure levels. Thereafter the latter fluids are used to provide reactive thrust or expanded in an expansion machine or employed in some other convenient way.

The relationship between the spacing of the cell partition walls 5 and the width of the ducts 9, 9', 10, 10', has been previously discussed in relation to other pressure exchanger proposals. As shown in Figure 3, e.g. at 14 and 14', the end plate walls have distinct parts which provide duct passages from one another and which provide that communication between any cell and the ducts shall be intermittent. It is preferred that this should be so even when one end of all the cells is opened only to a common fluid pressure level. The duct passage openings in the end plate walls are preferably so located that an end of a cell is closed by the end plate wall substantially at the instance of arrival at that cell end of a compression or expansion impulse caused by the other end of the cell being closed. It is also preferable that an impulse caused by an end of a cell being opened to a duct passage should reach the other end of the cell at the instant when that other cell end is opened to its passage. Although it is not possible to define as closely as one would wish the instant at which a cell passes a duct passage edge and thereby gives rise to an impulse in the cell, it is desirable that a cell should remain in contact with a duct for a period equal to the time required for an impulse to travel from one end of a cell to the other and back again or an integral multiple thereof.

The parts of the end plate walls between various duct passages leading to and from the cell wheel may not be of equal width due to the fact that depression impulses become extended in length when travelling through the cell and compression impulses are decreased in length. Considering this in connection with Figure 3 there will be seen there an end plate structure 11 having a wall adjacent the cell wheel 14. At the other end of the cell wheel there is the end plate having a part of the wall between adjacent passages shown at 14'. The impulse due to the closing of a cell by the end wall part 14 has to reach the other end of the cell at the moment when the end plate wall 14' is closing the same cell. However, when a cell passes the end plate wall 14 and is opened thereby the impulse travelling to the other end of the cell has to reach there at the same moment when the cell is being opened by the end plate wall edge 14'. As the rotation of the cell wheel is at constant angular velocity and the times for the impulses to travel through the cell are different the widths of the end plate wall sectors 14 and 14' are preferably themselves different for efficient operation.

Consider higher pressure fluid entering into the pressure exchanger of Figure 3 in the direction of the arrows 16 through the entry passage 10. In the left hand cell of the peripheral development of the cell wheel there is fluid at a pressure lower than the fluid entering through the passage 10, and its other end opening to passage 9' is also at a lower pressure hence the fluid in the cell is accelerated. The higher pressure fluid entering the cell sets up an acceleration impulse which is able to pump the fluid in the cell to the pressure level obtaining in the duct 9' which is assumed to be higher than that in duct passage 10'. Fluid therefore leaves the cell in the direction of the arrow 15'. On connection of the same cell to the

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outlet passage 10' and to the inlet duct 9 where a lower pressure obtains the pressure difference between the ends of the cell changes sign and retardation of the fluid flow is caused. However a depression exists at the upstream end of a cell as it becomes opened to passage 9 and fluid continues to enter the pressure exchanger. At the downstream end of the cell fluid is discharged into the passage 10' in the direction 16'. The cell proceeds on its way and once again it becomes open at its upstream end to a fluid of higher pressure through the next duct 10 and an acceleration impulse pumps the fluid in the cell out through the next outlet passage 9'.

The high pressure fluid supplied to the pressure exchanger may conveniently be the hot combustion products from a combustion system. Where this is so and the lower pressure fluid is atmospheric air there is a very useful application of this machine to gas turbine plant in a manner which will be described in more detail below.

In the embodiment of the invention illustrated in Figure 4 it will be seen that there is only one end plate proper, namely that shown at 18 which carries ducts 19 and 20 for fluids at two different pressure levels entering the pressure exchanger. In this diagram it is more clearly shown how the entry duct 20 is bifurcated upstream of the pressure exchanger, fluid supplied therefrom going to diametrically opposed duct passage openings in the end plate adjacent to the cell wheel. The cell wheel rotor 21 is supported by a shaft 22 which runs in bearings 23 and 24. The cells 25 themselves are of more complicated from than those shown in the embodiment above in that they are partly conical. Their downstream ends open into a common discharge orifice 26 through which fluid leaves the pressure exchanger. As in the previously described embodiment two fluids at higher and lower pressure levels enter the device by the ducts 19 and 20 respectively which alternate peripherally around the annular entry into the cells 25 through the end plate 18. The common duct terminating in the discharge orifice 26 is in this case maintained at a pressure intermediate between the two inlet pressures and the fluid leaves the cells at that pressure. Pressure is immediately transformed into velocity but in operation it can be considered that a pressure difference exists across the ends of each cell. An embodiment very similar to that shown in Figure 4 can be clearly envisaged in which it is the end plate structure which rotates to a stationary cell wheel. Such a possibility is illustrated by the mating together of the rotating and stationary parts of the inlet duct 20 by the peripheral surface 27 running within the stationary bearing surface at the end of the duct 28. This arrangement will not only permit rotation but will take up axial displacement of the end plate. A labyrinth seal or the like would be included in this arrangement. If it is so desired the orifice 26 may be shaped as a nozzle so that the fluid leaving the pressure exchanger can expand and accelerate.

While the two embodiments described above have been pressure exchanging and pressure equalizing arrangements, that shown in Figure 5 is a pressure dividing arrangement. A rotary cell wheel 29 is formed integrally with the ducting through which fluid is passed to the cell wheel. Fluid enters the cell wheel in this case at one pressure level only. Also integral with the cell wheel itself is a cylindrical duct 31 into which is discharged fluid at one of the two outlet pressure levels. In this instance it is the end plate which is rotatable relative to a stationary cell wheel, the end plate being shown at 32. It comprises ducts 33 for fluid leaving the pressure exchanger at a different pressure from that of fluid leaving through the cylindrical duct 31. The end plate is supported by a shaft 37 which runs in bearings 35. The outlet duct passages 33 join into a common conduit 36 in which there is maintained a pressure level either higher or lower than the input pressure level.

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In Figure 5A there will be seen a diagrammatic perspective view of the end plate 32, showing in particular the arrangement of the outlet ducts. The two ducts 33 in the upstream end of the end plate allow fluid to pass through to the common outlet conduit 36. The two other diametrically opposed ducts 33' allow fluid to pass to the outside of the end plate 32 halfway along its length. Referring back to Figure 5 it will be seen that this allows the fluid taken through these ducts to be discharged through the cylindrical duct 31. The duct 31 and the conduit 36 are maintained at two different pressure levels one above and the other below the input pressure level to the pressure exchanger.

The embodiment shown in Figure 5 therefore provides a pressure divider one part of the fluid entering into the pressure divider having imparted work to another part of the same fluid. Fluid enters the pressure divider at a medium pressure and is delivered at the other end of the cell wheel into alternatively arranged duct passages one group being at a higher pressure and the other at a lower pressure than the entering pressure. When the downstream end of any cell is connected to the lower pressure outlet duct there is an acceleration of the fluid in the cell and when it is connected with the higher pressure duct then there is deceleration of the fluid. Hence, one part of the entering fluid pumps or compresses another part of the same fluid to a higher pressure while that part which has performed the work leaves at reduced pressure.

It is possible to allow the fluid to expand by increasing its speed before leaving the pressure exchanger. In such a case of course, the pressure at which the fluid leaves the exchanger will be lower than it would otherwise have been.

Although in the aforedescribed embodiments not more than two groups of ducts are provided at each end of the cell wheel for the ingoing or for the outgoing fluids, it is nevertheless possible without basically modifying the process or the apparatus, to provide in the end plates, more than two groups of ducts separated by partition walls. Such an apparatus in accordance with the present invention is then capable of taking in fluids at more than two pressure levels and delivering fluids at more than two different pressure levels.

The pressure exchangers described above may be combined in many ways with other similar apparatus or with different apparatus. For example, pressure exchangers may be connected in series and they may be combined with combustion processes or heat introduction or abstraction in different forms. Some of the possible ways of use of the different embodiments of the invention described above will now be set forth. Reference will be made to Figures 6 to 10 which all show applications of the present invention. In Figure 6, 38 is a pressure divider, air entering at 41 and leaving at 42 at a higher pressure and at 43 at a lower pressure. At 40 is a combustion chamber, or other heating means, in which the air entering at 42 is heated, leaving at an elevated temperature through the duct 45. The higher and lower pressure gases are brought together through the ducts 44 and 45 in a pressure equalizer 39, from which the gases are discharged into duct 46, at a pressure higher than prevails at the intake 41. The compressed hot gas at 46 may be utilized to expand through a nozzle and produce thrust, or it may be led to an expansion machine, e.g. a turbine 47, through a duct 48. Useful work is produced and the exhausted gas leaves at 49.

The gas leaving the pressure exchanger 39 may be abducted therefrom, according to an alternative scheme, at two pressure levels; one of which, at 49A, is ambient pressure. This facilitates scavenging and results in a higher efficiency than if the exhaust pressure was above ambient pressure.

It is also possible as a further alternative to take in at 70 ambient air e.g. in order to be able to increase

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the temperature at 45 without raising the resulting temperature of the pressure exchanger 39.

Supercharging and scavenging of an internal combustion engine for instance two stroke engines, can also be performed by pressure exchangers in a manner based upon the Figure 6 layout. In fact, apparatus taking in gas and delivering it at a higher temperature can be supercharged by a pair of pressure exchangers arranged with the apparatus in place of the combustion chamber 40 of Figure 6. Thus any process such as the firing of a boiler and certain chemical processes can be supercharged as described. The device to be supercharged may advantageously be by-passed by a conduit provided with control means 71 by which it may be throttled or entirely closed.

In arrangements in which pressure exchangers are applied in connection with a turbine, or other expansion machine, to produce mechanical work, the turbine may be so positioned so that unheated gases only flow through it. This arrangement is illustrated in Figure 7 where the turbine 47 is situated in the gas flow between the pressure divider 38 and equalizer 39. The gas enters the turbine at 43 and leaves at 44, with a corresponding drop in pressure. Since the combustion products do not pass in this case through the turbine the arrangement would permit the use of fuels normally excluded because of damage they are expected to cause to the turbine e.g. pulverised coal may be burnt in the combustion chamber 40.

In another alternative arrangement the turbine 47 may work in parallel with the pressure divider, as in Figure 8 the air entering into the turbine in a parallel branch of 41, and leaving at lower pressure. The air leaving the turbine is taken into the pressure equalizer at the same pressure as prevailing in conduit 44, or at a similar pressure level.

The high pressure fluid supplied to a pressure exchanger may be hot gas exhausted from a compressor-turbine set, which it leaves at a pressure above that of the ambient air as is the case in a jet engine. Such gas entering the pressure exchanger, e.g. at 20 on Figure 4, together with low pressure fluid in the form of ambient air entering at 19, can compress the latter and supply gas into a receiver at higher pressure than that of the ambient air. After this the gases can be made to expand through a nozzle orifice (e.g. 26, Figure 4), into the surrounding atmosphere to produce reactive thrust. By such a combination the propulsive efficiency and the thrust are raised, especially at the lower range of speeds at which the engine is moved through the atmosphere.

A schematic arrangement for the purpose described is shown on Figure 9. A compressor 50 is driven by turbine 51 with the combustion system 52 in between. The air enters at 53, leaves the compressor at 54, and after taking up heat enters the turbine at 55, from which it emerges somewhat expanded at 56 and enters the pressure equalizer 57. An ambient air supply is taken in at 58, is compressed in the pressure equalizer and both streams leave together at 59, producing thrust. Alternatively of course, the stream may be expanded in a second turbine as in a turbo-propeller engine. In another arrangement two streams may leave from a pressure exchanger substituted for the equalizer 57.

A further alternative scheme is shown in Figure 10. Here the air entering the compressor 60 at 61, and leaving same at 62, is heated in a combustion system for example at 63 and is led into the pressure equalizer 64 at 65. Air is also taken into the equalizer at 66. The gas leaves the pressure equalizer at 67, enters turbine 68, which drives the compressor and emerges therefrom at 69. If the production of jet thrust is the purpose, then this is produced by the flow at 69; if work on a shaft is to be produced, then this can also be achieved in well known manner. In this alternative the temperature at 65 can be very high, since it is brought down to an

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acceptable figure by dilution with the incoming air at 66. Thus neither the turbine 68 nor the pressure equalizer are exposed to excessive temperatures.

This method of reducing the temperature of a gas, without excessive loss of mechanical work available, by diluting a hot gas with a cooler one in a pressure exchanger, is generally applicable. For instance, it makes possible a powerful reheat between the turbine 51 on Figure 9 and the pressure exchanger, or after the pressure exchanger, by which the thrust will be increased further. Since the pressure exchanger receives also cool ambient air, the high reheat temperature will cause no harm in the device.

The fluids employed in pressure exchangers according to the invention may be gaseous or liquids or both combined. It is expected to be possible for instance, to pump by a gas of higher pressure, liquid from a lower pressure to a higher pressure or it can be accelerated to a higher speed.

What I claim is:

1. A pressure exchanger in which gas compression and gas expansion proceed simultaneously comprising a first cylindrical structure having cells around the periphery thereof, a second structure including an end plate adjacent one axial end of said first structure, means for effecting relative rotation between said first and second structures, a plurality of segmental outlet ports in said end plate, together occupying substantially the whole circumferential extent of said end plate and each outlet port being of such circumferential width that in the design conditions of operation wave action initiated within the cells by a leading port edge affects the complete axial length of a cell in both forward and reverse direction, and wall sections in said end plate between adjacent ports each of substantially the same circumferential width as a cell.

2. A pressure exchanger as claimed in claim 1 and comprising a single inlet duct forming part of said second structure and communicating with said cells at their ends opposite said one end.

3. A pressure exchanger as claimed in claim 1, in which said second structure includes an additional end plate adjacent the axial end of said first structure opposite to said one end, at least one segmental inlet port being provided in said additional end plate, the port width occupying substantially the whole circumference of the additional end plate.

4. A pressure exchanger as claimed in claim 3, in which a plurality of said inlet ports are provided, wall sections in said additional end plate between adjacent ports each being of substantially the same circumferential width as a cell and in which said inlet and outlet ports are staggered circumferentially.

5. Apparatus comprising first and second pressure exchangers, said pressure exchangers comprising cells in which gas expands so compressing another part of that gas with which it is in direct contact, said cells forming a continuous boundary for the gas flowing through them and extending in the direction of gas flow ducting to lead gas to and from the cells at different pressure levels, and means to effect relative motion between the cells and the ducting, the first pressure exchanger receiving gas through said ducting at a first pressure level and discharging said gas through said ducting at two pressure levels one higher and the other lower than said first level, said apparatus further comprising a gas heating system receiving gas at said higher pressure level directly from the first pressure exchanger and discharging hot gas, and the second pressure exchanger receiving said hot gas directly from the heating system together with gas discharged at said lower pressure level from the first pressure exchanger and discharging a stream of hot gas.

6. A heat engine incorporating pressure exchanger apparatus as claimed in claim 5 and in which an expan-

sion machine is provided through which said stream is expanded to perform useful work.

7. A heat engine incorporating pressure exchanger apparatus as claimed in claim 5 in which said second pressure exchanger has three inlet ducts, a first duct to receive said hot gas from said gas heating system, a second duct to receive gas discharged at said lower pressure level from said first pressure exchanger and a third duct to receive a further gas supply at a low temperature compared with said hot gas whereby greater heat may be introduced via the heating system than would otherwise be permissible.

8. A heat engine incorporating pressure exchanger apparatus as claimed in claim 5 modified in that an internal combustion engine required to be supercharged at said higher pressure level and scavenged is substituted for said heating system.

9. A heat engine incorporating pressure exchanger apparatus as claimed in claim 5 in which said second pressure exchanger has two outlet ducts, a first duct for said hot gas stream and a second duct for a second output stream of gas at a lower pressure level than said discharged hot gas.

10. A pressure exchanger in which gas compression and gas expansion proceed simultaneously, comprising a first cylindrical structure having cells around the periphery thereof, an inlet duct through which fluid enters the cells at one end of said first cylindrical structure, a second structure including an end plate in juxtaposed relation to the other end of said first cylindrical structure, means for effecting relative rotation between said first and said second structures, the fluid in the cells of said first structure being subjected to acceleration and deceleration impulses to create pressure differences between opposite ends of the cells in the said first cylindrical structure, said end plate having a plurality of outlet ports and ducting communicating with said outlet ports for the passage of fluid from the cells of said first cylindrical structure to alternate outlet ports and ducts at pressure levels respectively above and below the pressure of the fluid in the inlet duct of said first cylindrical structure.

11. A pressure divider in which gas compression and gas expansion proceed simultaneously, comprising a cylindrical structure having cells around the periphery thereof, an inlet duct through which fluid enters the cells at one end of said cylindrical structure, an end plate in juxtaposed relation to the other end of said cylindrical structure, means for effecting relative rotation between said end plate and said cylindrical structure, said end plate having therein a plurality of outlet ports communicating with said cells, wall sections in said end plate separating said outlet ports, the width dimensions of said outlet ports, wall sections and cells being of such magnitudes relative to each other that in the designed conditions of operation the fluid from said inlet duct is delivered to alternate outlet ports via said cells at pressure levels respectively above and below that of the fluid in said inlet duct.

12. A pressure divider in which gas compression and gas expansion proceed simultaneously, comprising a first cylindrical structure having cells around the periphery thereof, an inlet duct through which fluid enters the cells at one end of said first cylindrical structure, a second structure including an end plate in juxtaposed relation to the other end of said first cylindrical structure, means for effecting relative rotation between said first and second structures, said end plate having therein a plurality of segmental outlet ports which together occupy substantially the whole circumferential extent of said end plate, each outlet port being of such circumferential width that in the design conditions of operation the fluid in the cells is subjected to acceleration and deceleration impulses initiated by the leading and trailing edges of the outlet ports which impulses create pressure differences between opposite ends of said cells, ducting communicating with

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said outlet ports, wall sections separating said outlet ports in said end plate, said wall sections being of substantially the same circumferential width as said cells, the width dimensions of said outlet ports, wall sections and cells being of such magnitudes relative to each other that in the designed conditions of operation the fluid from said inlet duct is delivered to alternate outlet ports via said cells at pressure levels respectively above and below that of the fluid in said inlet duct.

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Front Cover Art: Pangu and the Egg of Yin and Yang, from
   which He Created the World. 17th Century Chinese woodcut.

Back Cover: Hiscox, Gardner Dexter. Mechanical Appliances.
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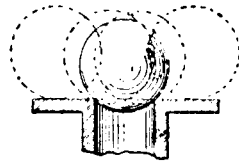
333. PNEUMATIC BALL PUZZLE. A ball laid on the mouth of a flanged tube, as in the cut, can not be blown off by an air jet, but will continue to roll around on the flange, as shown by the dotted lines.

334. PNEUMATIC DISK PUZZLE. A light circular plate with pin guides can only be lifted a small distance by an air jet from the flanged tube. The theory is that the momentum of the air as it suddenly spreads to a larger circumference causes a partial vacuum near the outer edge, thus holding the plates so near together that their circumferential area corresponds with the area of the central jet.
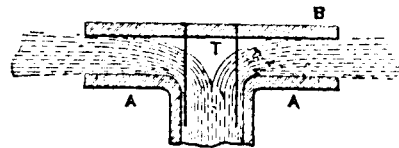
335. PNEUMATIC BALL PUZZLE. A light ball is held in a jet of air from a vertical to an angle of about 30° and revolves with considerable velocity.
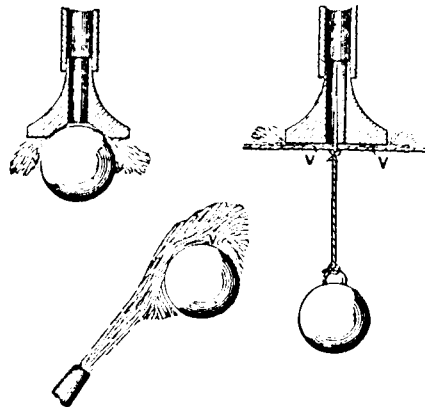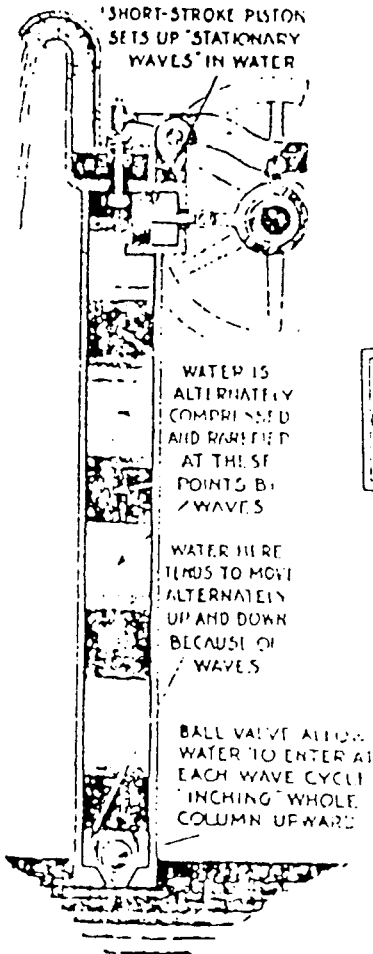
A light ball placed in a conical cup over a jet of air will be held there and not driven off when the cup and jet are reversed.

A card placed on an inverted flanged jet of air, as at V, V, will not drop, even with a considerable weight hanging to it.
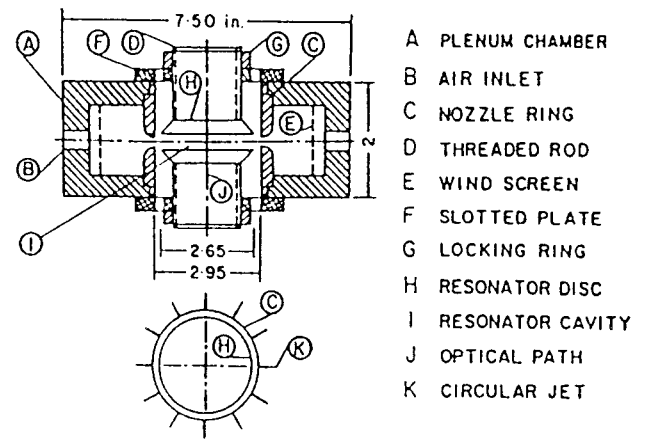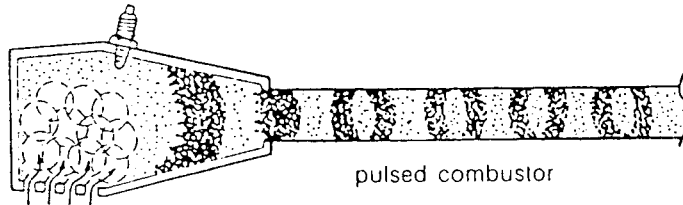
336. Inverted nozzle and ball.

337. Inverted nozzle with ball attached to plate.
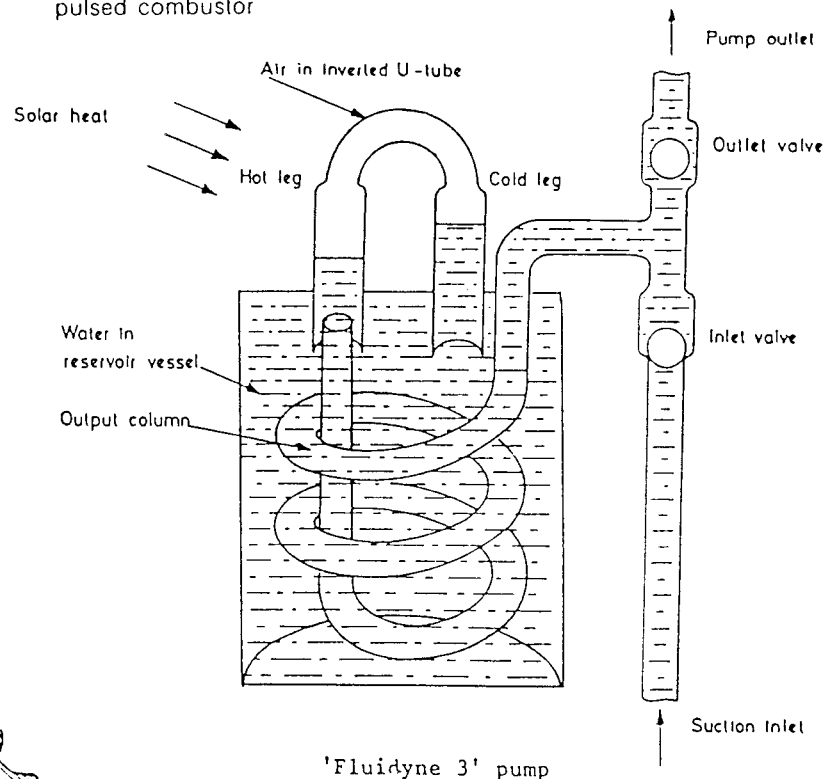
Compression Wave Pump

'SHORT-STROKE PISTON SETS UP 'STATIONARY WAVES' IN WATER

WATER IS ALTERNATELY COMPRESSED AND RAREFIED AT THESE POINTS BY WAVES

WATER HERE TENDS TO MOVE ALTERNATELY UP AND DOWN BECAUSE OF WAVES

BALL VALVE ALLOWS WATER TO ENTER AT EACH WAVE CYCLE 'INCHING' WHOLE COLUMN UPWARD

Pulse-jet aspirator

'Kylchap'

pulsed combustor

A	PLENUM CHAMBER	
B	AIR INLET	
C	NOZZLE RING	
D	THREADED ROD	
E	WIND SCREEN	
F	SLOTTED PLATE	
G	LOCKING RING	
H	RESONATOR DISC	
I	RESONATOR CAVITY	
J	OPTICAL PATH	
K	CIRCULAR JET	

7·50 in.

2·65
2·95

cylindrical resonator

Solar heat

Air in inverted U-tube

Hot leg   Cold leg

Water in reservoir vessel

Output column

Pump outlet

Outlet valve

Inlet valve

Suction inlet
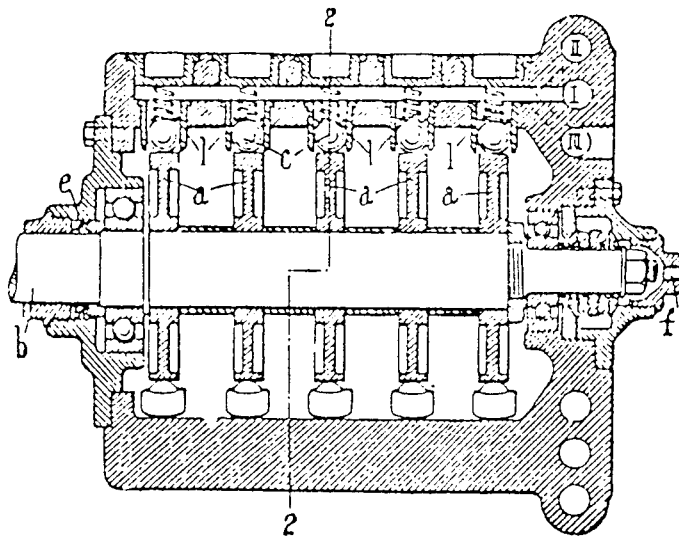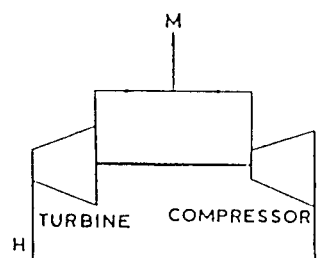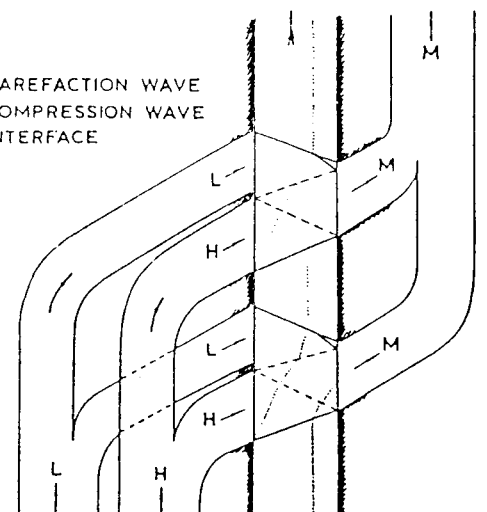
'Fluidyne 3' pump

G. CONSTANTINESCO.
SYNCHRONOUS ALTERNATING LIQUID CURRENT MOTOR.

MAXWELL'S DEMON:
THE LITTLE SHOCK
WAVE THAT COULD!

---- RAREFACTION WAVE
—— COMPRESSION WAVE
.... INTERFACE

M
TURBINE   COMPRESSOR

a equalizer, utilizing compressor-turbine set.

b equalizer, utilizing a two cycle DPE.

Equalizer